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BEHAVIORAL TECHNOLOGY LABORATORIES

Technical Report No. 86

Electrophysiological Correlates of Cognitive Activity: Event Related Slow-Potentials Developed During Solution of Anagrams

July 1978

Louis A. Williams
Joseph W. Rigney

Sponsored by

Personnel and Training Research Programs
Psychological Sciences Division
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Electroencephalographic (EEG) activity and time to solution were recorded for sixteen human subjects during a task requiring the solution of five letter anagrams. Solution achievement was signaled by depressing a microswitch. The sixty stimulus anagrams were selected from lists of abstractness and usage frequency to form four stimulus groups: (1) concrete/high frequency; (2) concrete/low frequency; (3) abstract/high frequency; (4) abstract/low frequency. Stimulus words were presented to

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subjects in a randomized order interspersed with a non-anagram recognition word (TANGO) or a blank screen (BLANK). Stimulus presentation was under computer control and displayed upon a computer CRT. Solution time was subjected to an analysis of variance. Abstractness and frequency were both significant. Abstractness had the greater effect upon solution time. There were no interaction effects. Concrete (low abstractness) anagrams were solved more quickly than abstract anagrams, with the effect of frequency of usage additive to solution times. This result was concluded to support, but not to confirm a parallel processing hypothesis: conscious processing concerned with anagram letter rearrangement, and simultaneous unconscious processing concerned with retrieval of possible solution words from long term memory.

The EEG was analyzed by Fourier methods to determine frequency and amplitude content. A coherence analysis was performed upon selected segments of the EEG pre and post response. Visual analysis of individual trials was accomplished through a computer developed super-imposition display. Displayed trials were organized by correct of incorrect solutions, failure to achieve solution (TIME-OUT), TANGO or BLANK presentations. The development of a negative shift following stimulus onset in all except BLANK trials was revealed. Trials in which a correct solution was achieved, or TANGO recognition occurred, showed a reactive shift to positivity at about 350 milliseconds latency. This identification was supported by the analysis of coherence. The negative shift was concluced to be similar to the Contingent Negative Variation (CNV). The positive shift was concluded to be a P300 wave. The CNV-like shift was related to selective attention-selective responding demands of the paradigm. The P300 was related to decision processes allowing a relaxation of attention and responding.

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Chapter I

INTRODUCTION

The past century has produced a remarkable fund of knowledge concerning the mechanisms of the Central Nervous Systems (CNS) of the human and animal alike. A more tenuous knowledge has been gained concerning the relationship of these known mechanisms to the overt and covert behaviors that the organism may exhibit in either the laboratory or daily environment.

Luigi Galvani's discovery in 1790 of the electrical excitability of neural tissue created a new region of physiological investigation. The advances in the methods of generation and measurement of electrical currents that followed gave a new insight into the nature and complexity of neural electrochemistry. In 1875, Richard Caton published an account of the recording of electrical potentials from the brains of rabbits. In 1929, Hans Berger recorded the electrical activity of the human brain and identified the rhythmic activity of the cortex. Berger also named the record of brain activity the Electroencephalogram (EEG). The study of the EEG expanded in new directions through the 1930's. Psychological correlates of brain activity came under scrutiny. The physiologically oriented psychologists utilized this tool to investigate the relationship of brain electrical activity to sensory experience, perception, learning, emotion, motivation, and a myriad of other behavioral phenomena.

The rapid advance of technology in the field of electronics that followed the second World War, and particularly the development of the digital computer, again expanded the experimental horizon of the psychologist in this research area. The oscillatory activity of the alpha, beta, or other waves could seldom be related to behavior in sufficient specification. Highly sensitive amplifiers, capable of sensing and developing signals of only a few microvolts, revealed the existence of the Evoked Potential (EP). This activity of the brain is produced in fixed temporal relationship to sensory input, and is said to be evoked by that input. The EP is so small in amplitude as to be difficult to measure or to separate from ongoing activity in most cases.

Systematic investigation of this phenomena became feasible when Dawson (1954) suggested separating the EP from ongoing activity by the signal enhancement technique of summating the EEG record over trials. This process relies upon the consistent temporal relationship of the evoked potential to the evoking stimulus. It is known that time-locked activity, or the "signal" of interest, summates directly as the number of repetitions of the event. Activity not locked in time to the event, constitutes unwanted "noise" and summates only as the square root of the number of repetitions. The summation technique provides a means of improving an adverse signal-to-noise ratio, and extracting very small signals from inherently noisy environments such as the brain.

Current research considers two basic types of evoked potentials; the so-called alternating current (a.c.) potentials and the direct current (d.c.) potentials. The d.c. potentials are slower and seldom demonstrate the periodic components of the a.c. potentials. These d.c. potentials require more sophisticated recording techniques than the a.c. potentials in order to prevent the distortion of the signal by the detection and amplifying equipment.

The differences between potentials that can be related to distinct stimuli or to motor acts, and those which cannot be so distinctly related, has led to the general acceptance of the term Event Related Potentials (ERP) for those of the first group. The ERP's are then further divided into groups dependent upon the a.c. or d.c. nature of the potential. Those more d.c. in nature have been termed Event Related Slow Potentials (ERSP) and have themselves been separated into four main categories. These categories have been described by Vaughn (1969) as: (1) sensory evoked potentials, (2) motor potentials, (3) association cortex potentials, (4) steady potential shifts. The first three are relatively well synchronized with their reference events, and can be localized as to intercranial source of the signal. The steady potentials form a less distinct category due to their uncertain origins and the rather nebulous psychological associations with which they have become endowed. The ERSP's were first described in man by Kohler, Held, and O'Connell (1952), but became the subject of wide interest following the description by Grey Walter and his colleagues (1964) of the Contingent Negative Variation (CNV).

A complete review of the history and research that has followed the initial description of the CNV has been admirably accomplished by Tecce (1972).

The initial findings of Walter were confirmed by Low, Borda, Frost and Kellaway (1966); Rebert, McAdam, Knott, and Irwin (1967); and Cohen, Offner, and Blatt (1965). Since these confirmatory studies, interest in this area of research expanded rapidly. Four International meetings have occurred dedicated to the interchange of ideas and research methods concerning this most intricate of brain responses.

The Second International CNV Congress of 1971 pointed out several aspects of ERSP research that required detailed attention. W. Grey Walter, in the opening address to the Second Congress, pointed out the need for an improved technology for recording single trial events. The need for averaging to improve the signal to noise ratio also eliminated observation of the trial to trial variability. W. C. McCallum, (in whose EEG the first CNV had been seen) in addressing the relationship between CNV and Human behavior, noted the limitations that had been imposed upon the stimulus events in most research. The artificiality of the usual laboratory stimuli (tones, clicks, and flashes) failed to represent the more diverse information processing that is present in the usual waking activity of the human being. McCallum pointed out several aspects of research methodology in ERSP investigations that clouded the view of the relationship between brain electrical activity and the behavior manifested by the subject. Among these were: imprecise psychological constructs with which researchers had encumbered themselves; and artificial and irrelevant laboratory situations that failed to correspond to the normal activity of the subject.

To a great degree, these criticisms of ERSP research have been dictated by the need to average over trials in order that the potential of interest could be seen and extracted from the total data. When utilizing complex verbal or visual stimuli, subtle differences between stimulus items of the same general category may determine the internal processing rate. The resultant ERSP may no longer be time locked to the stimulus and therefore not subject to averaging for signal enhancement.

Weinberg (1976) questioned the "reality" of the averaged signal utilized in most investigations, noting the loss of information concerning ERSP variability from one trial to another that resulted. Weinberg also noted that averaging methods were unable to provide information about the central tendency of the ERSP with respect to amplitude or phase differences that occurred. The implication is that the importance of each signal is determined by its relationship to the mean or average of many similar signals. The departure of an ERSP in some parameter from the average may constitute the data of interest and be related to difference in behavior more than the average data is to average behavior.

The requirement for averaging has placed focus upon the temporal relationships of the ERSP with an unfortunate emphasis upon the element of temporal consistency. The process of averaging tends to eliminate potential changes that occur with differing latencies, and to remove such signals from the realm of investigation.

The solution to the problem is certainly not trivial. A concentration upon more adequate detection and recording techniques would provide only a starting place. When single trial recording of ERSP's could be coupled with real time analytical methods available with high speed computer systems, only then could these more subtle relationships be more adequately investigated.

Recognition of the importance of this research direction provided the incentive to undertake the development of a basic system for the recording of ERSP's in the single trial. A system utilizing a Direct Current amplification system for this recording is described in a separate report. The utilization of this system is an experimental setting is discussed in the chapters to follow.

Chapter II

THE EVENT RELATED SLOW POTENTIALS IN RESEARCH: DERIVATION and VALIDITY

Two relatively recent neurophysiological discoveries: the contingent negative variation (CNV) brain wave (Walter, Cooper, Aldridge, McCallum, & Winter, 1964); and the P300 brain wave (Sutton, Braren, Zubin, & John, 1965) appear capable of providing researchers with neuropsychological indices of cognitive activity within the human brain. Since 1964, a developing body of CNV research findings has associated this neurophysiological measure to psychological concepts: expectancy (Walter, 1965; Walter et al., 1964), learning (McAdam, 1966), conation (Low, Borda, Frost, & Kellaway, 1966), motivation (Irwin, Knott, McAdam, & Rebert, 1966; Rebert, McAdam, Knott, & Irwin, 1967, preparational set (Low et al., 1966), attention (McCallum, 1969; Tecce, 1970; Tecce & Scheff, 1969), concentration (Donald, 1970), reactive change (Karlin, 1970), and brain activation (Naatanen, 1970; Tecce, 1971, 1972).

Cohen, Offner, and Blatt (1965), Hillyard (1968), Hillyard and Galambos (1967), and Low (1966) have confirmed the existence of the cortical slow wave electrical phenomenon termed CNV through replication of the original Walter et al., (1964) paradigm and recording conditions.

Hughes (1968), reviewing electroencephalography and learning, stated: "Thus, the CNV wave may be destined to be the first very reproducible, specific and distinctive electrophysiological correlate of higher mental function in man (p. 122)."

Lindsley (1969b) noted that the CNV may be important from the learning point of view, particularly in relation to application of instructional technology techniques. His observation is that students do not learn as much from visual and auditory aids as anticipated by researchers, perhaps due to passivity. His recommendations are to determine if development or iteration of the CNV is fundamental to the human learning process by converting brain passivity, during usage of these devices, into expectancy and involvement.

The P300 brain wave component (Sutton et al., 1965), might also serve as a neuropsychological indicant of human cognitive activity. Beginning in 1965, Sutton and colleagues (Sutton et al., 1965; Sutton, Tueting, Zubin, & John, 1967; Tueting, Sutton, & Zubin, 1971) began to demonstrate that P300 component of the vertex evoked potential was present when the stimulus delivered information, and was reduced or absent when the stimulus was redundant.

Some formulation of the psychological processes associated with the P300 have been suggested. Ritter and

Vaughan (1969) suggest that the P300 is an indicant of the reaction of orienting and cognitive activity of the brain. Smith, Donchin, Cohen and Starr (1970) have proposed the P300 in association with a "decision regarding the stimulus." Sutton (1971) stated: "The P300 component of the averaged evoked potential recorded at the vertex is highly sensitive to the 'salience' of the stimulus to the subject (p. 302)." Squires, Hillyard, and Lindsay (1973a) inferred that the P300 reflected the certainty of decision making based upon the signal information previously received. Karlin (1970), however, associated the evocation of the P300 to a: ". . . reactive change in preparation after presentation of the critical stimuli (p. 122)." Jenness (1970), based upon his recording of P300 development over trials in a difficult learning task, suggested that this large late vertex component was the first endogenous (originating within the brain), i.e., stimulus independent brain wave component to be reliably identified in the evoked potential literature.

Cortical Architecture and the ERSP

The CNV as discovered by Walter et al., (1964) has been associated with the frontal cortex in man. Walter (1964) stated that the function of the CNV could be described as priming the frontal cortex. Walter (1965) has observed the CNV waves sweeping from the frontal pole toward the premotor zone during the 0.5 second or so between the conditional response and the imperative responses. Walter (1965) suggested: "The essence of the effect, orienting and habituation, is that the frontal responses are a part of the orienting or Novelty Response . . . (p. 3)."

Luria (1973), based upon a 30-year study of war damaged brains, including damaged frontal lobes, suggested:

> These data show that the frontal lobes play an essential part in the higher forms of regulating the states of activity. They control the active state of the cortex, which is necessary for the accomplishment of complex tasks, and play an important role also in the execution of intentions that determine the direction of human activity and impart to the latter an elective and purposive character. Numerous observations have also revealed the role of the frontal lobes in the execution of complex programs of activity, the formulation of the orienting basis of action, and the organization of its strategy. Further, their role in the process of matching the effect or consequence of action to the initial intention which is the basis of the highly important function of the modification of action (p. 22).

Pribram (1973), in summarizing collective data regarding the function of the frontal lobes, stated:

> I feel reasonably sure that the dorsolateral frontal cortex, like the limbic formations of the forebrain (including the medial and orbital frontal cortex), are concerned in the inhibition of interferences among brain events. With respect to lesions of the frontal cortex, this involvement becomes manifest on the input side as a difficulty in attention, a difficulty in registering novelty so that habituation, or assimilation, fails to take place. On the output side, the feedback to actions from their outcomes is impaired and reinforcers become relatively ineffective (p. 306).

A detailed review has not been attempted concerning the investigative, experimental studies of the neuropsychological and neurophysiological characteristics of the frontal lobes. Additional information and extensive bibliographies may be found in Luria and Homskaya (1970), representing the Russian viewpoint, and Pribram and Luria (1973), representing, collectively, the Russian and Western viewpoints. Luria (1970) presents the functional roles of the frontal lobes and the relationships of these functions with other functional aspects of the brain. Clark and Dewhurst (1972) present an interesting overview of the frontal lobes in relation to other cortical functions.

<u>Input-Output Reciprocity: The Routtenberg Theory</u>

Routtenberg (1968, 1971, 1972) postulated that two major systems form the substrate for behavioral acts: System I, associated with the reticular formation, and System II, associated with the limbic midbrain structures. System I subserves <u>output</u> processing whereas System II subserves <u>input</u> processing. Routtenberg views these two systems as having a reciprocal and inhibitory relationship. A description of the functional reciprocal and inhibitory interrelationship of these systems and their resultant behavioral influences perhaps is best understood in the explanation given by Routtenberg (1972):

> To recapitulate, the reciprocal relation between the two systems is not a totally inhibitory one. The suppression of System I by System II occurs as a consequence of particular stimuli; hence, those responses that are irrelevant to the processing of such stimuli, or that would subsequently interfere with the appropriate response to those stimuli, are inhibited. The responses relevant to the further processing of related stimuli are not inhibited. The stimulus processing of System II, while controlling the majority of responses under System I direction, does not control all responses; stimulus processing therefore leads to response selection. Response processing, on the other hand, does not inhibit all stimuli, but selects by not inhibiting those stimuli whose processings are relevant to the execution of a particular response. The response function of System I, has as one of its consequences stimulus selection or selective attention; that is, those stimuli that are irrelevant or potentially disruptive to the performance of that response are gated by System I, permitting relevant stimuli to be maximally effective (pp. 161-162).

Thus we see proposed that performing an action leads to <u>stimulus selection</u> or <u>selective attention</u>, and stimulus processing initiates <u>response selection</u>.

Some support for this reciprocity of afferent and efferent linkage is proposed by Sokolov (1963) in explaining that repetition of presented stimuli resulted in <u>selective</u> extinction of the orienting reflex and inhibition of the orienting reflex to <u>extraneous</u> parts of the stimulus structure.

> The process of generalization of excitation in the afferent and efferent links of the orientation reflex--when it enters into the structure of the conditioned reflex--are interconnected, and depend on the functional characteristics of the conditioned connection. For instance, repetitive application of

> a series of stimuli, similar to the signal, eventually results in the progressive extinction of various elements of the orienting reflex, which thus becomes restricted to specific reactions based on the analyser actually stimulated. This leads to efferent concentration. At the same time, however, a number of related stimuli which have not been applied also lose their effects. This is the result of afferent concentration of excitation in the area of representation of the conditioned stimulus. The interdependence of the processes of afferent and efferent concentration results in the specialization of the orientation reaction, associated with the restriction of the conditioned response to only definite, signal stimuli (p. 241).

Routtenberg (1972) applies his integrative neurobiological theory to memory as an input-output reciprocity process. This memory process is predicated upon System I, the output processing mechanism, and System II, the input processing mechanism. In his schema, Routtenberg proposes that System II initiates memory storage and System I initiates memory retrieval. Of particular interest to cognitive research is his position that neither information storage nor information retrieval can proceed without the other in terms of the total memory process. Paradoxically, however, one cannot operate if the other is active. Routtenberg (1972) accounts for the paradox when he proposed that there is rapid oscillation between the two functions:

> Sensing the functional consequences to determine what it, in turn, should do next. The reciprocal relation between the two systems indicates that certain structures, when storing information, are prevented from enacting the retrieval mode; and when engaged in memory retrieval, storage is not permitted (pp. 166-167).

Routtenberg (1972) summarized the relationship of System I and System II functions to the mechanisms of memory as follows:

> . . . the two functions are interdependent, each requiring the other to function. Thus, activity of System II storage mechanisms would allow for refined or narrow selective retrieval. Activity of System I retrieval mechanism could allow for the selective deposition of memory trace. Contained in this thought is the view that memory storage is selective, else it would be occlusive; memory retrieval is narrow and defined else it would be unintelligible (p. 167).

Electrophysiologically, Routtenberg took the position that System I activation is indicated by hippocampal low voltage, fast activity (hippocampal desynchronization). Activity of System II is indicated by hippocampal high voltage slow activity (hippocampal synchronization) possibly indicated by theta wave activity. Based upon the work of O'Leary and Goldring (1964), Routtenberg saw an association between hippocampal theta activity, and the cortical slow wave shift; that is, System II activity is associated consistently with slow wave alterations in the cortex which depresses some cortical activity and enhances other activity.

<u>Evoked Potentials: Characteristics and Validity</u>

MacKay (1969), defined evoked electrical brain potentials when he stated:

> The term "evoked brain potentials" (often abbreviated to EP's) is generally used to denote (electrical) signals in the latter class (diffuse

> and slowly changing electric fields) that result from (or at least covary with time-locked) stimulation of sense organs or afferent pathways, whether or not the stimulus is sensed by the subject (p. 187).

John (1967) explained evoked potentials or evoked brain electrical responses as a synchronous volley of electrical brain impulses produced by afferent or sensory stimulation giving rise to macropotentials, in both cortical and subcortical structures, when time-locked to the stimulus. Time-locking principally refers to the initial time of presenting the stimulus. Upon initial presentation of a chosen stimulus, the evoked brain potential or response is evoked concurrently with the initial stimulus presentation. The electrical response to the stimulus may outlast the stimulating period.

John (1967) stated:

> Some of the "evoked potentials may be rather distinct while others may be obscured by the ongoing (natural, spontaneous) background (brain electrical) activity and require (computer) averaging techniques to detect them" (p. 224).

This is an important differentiation; evoked brain potentials, as the term is used in electrophysiological research, refers to a distinct phenomenon differing from simple ongoing brain activity such as that of alpha activity or low voltage beta activity in that they are brain related electrical events initiated by and time-locked to an initiating stimulus presentation or event.

The phrases evoked potentials or evoked responses are used interchangeably in electrophysiological literature. Potential is the term drawn from electrical theory indicating the existence of a charge and determined by current flow in a circuit as referred to some standard; the standard used is voltage (Cooper et al., 1969).

Characteristic of Evoked Potentials.

Figure 1 depicts the morphology or shape of auditory evoked, visual evoked, and somatic evoked electrophysiological waveforms. The morphology of such waveforms are usually described by five parameters (Goff, Matsumiya, Alliston, & Goff, 1969; Vaughan, 1969): (a) modality, (b) polarity, (c) amplitude, (d) latency, and (e) topography. The morphology usually depicted is the averaged evoked potential derived by computer methods over a number of trials.

Modality. Electrophysiological potentials may be evoked within the brain through stimulation of various senses such as the auditory, visual, and somatic modalities. Extensive investigations have been made of the auditory evoked potentials (AEP) (Davis, Mast, Yoshie, & Zerlin, 1966; Gross, Begleiter, Tobin, & Kissin, 1965; Picton et al., 1971; Ritter, Vaughan, & Costa, 1968; Vaughan & Ritter, 1970; Wilkenson & Morlock, 1967), to name a few studies. Visual evoked potentials (VER) have

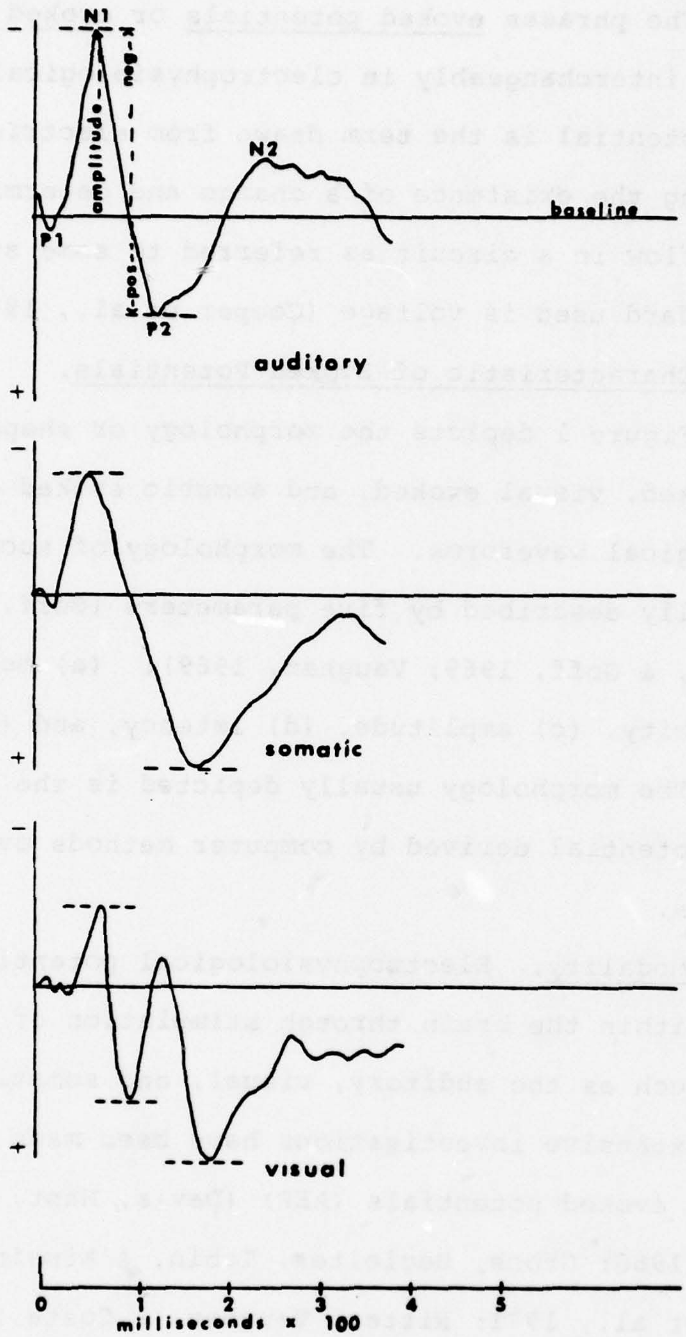


FIG.1 MORPHOLOGY OF THE AVERAGED EVOKED HUMAN WAVEFORM

been studied by many researchers; Chapman & Bragdon, (1964); Ciganek, (1961); Donchin & Cohen, (1967); Haider, Spong, and Lindsley, (1964); Spong, Haider, and Lindsley, (1965). Somatic evoked potentials have been studied by Donald and Goff, (1971); Goff, Rosner, and Allison (1962); and Klinke, Fruhstorfer, And Finkenzeller (1968), among others.

Jenness (1970) stated that the auditory and somaesthetic evoked waveforms are similar in morphology, but the visual evoked waveform is more complex. Goff et al., (1969), and Vaughan (1969), have provided extensive discussion of wave morphology.

Polarity. An electroencephalogram, or tracing of an evoked waveform is a biphasic curve, that is, it contains two phases. The trace is shaped by upward deflections and downward deflections above or below some neutral baseline which are changes of phase in electrical polarity; changing from a positive going direction to a negative going direction or vice versa. Electrical engineering standards were utilized in early research description, an upward deflection was positive and a downward deflection was negative. Currently, most studies now use the opposite convention; that is, an upward deflection is negative and a downward deflection is classified as positive. This is the neurological convention in place of the engineering standard.

As observed in Figure 1 the auditory, visual, and somatic evoked waveforms, due to polarity reversals, contain a series of peaks and troughs which are referred to as components. It is these components and their changes which are of major interest to evoked potential researchers. Investigators have related these components to stimulus, cognitive, and response related events. A particular component is usually described by three measurements noted by Vaughan (1969): (a) polarity, (b) amplitude, and (c) latency. Polarity then is a descriptor used to designate whether a given component is of positive (P) or of negative (N) orientation.

Amplitude. Amplitude refers to the amount of polarity deviation, or excursion, of a given component from an established reference point (Figure 1). Amplitude is stated in terms of voltage (microvolts, i.e., millionths of a volt, uv). Amplitude may be measured in two ways: (a) baseline, and (b) peak-to-trough. When utilizing the baseline measurement technique, one determines the average electrical activity over a period of time during a resting period, or just prior to presentation of the initiating stimulus. The amplitude value of a segment describes the amount of polarity deviation of the peak of a particular positive or negative component from the predetermined baseline reference.

A peak-to-trough or peak-to-peak (these two terms are interchangeably used in the literature) measurement does not use the baseline as reference in determining the amplitude value. Rather the range of the amplitude value of the total polarity excursion, or swing from the peak of one component to the trough of an adjoining component (or vice versa) is measured. Both of these evoked components measuring methods possess advantages and disadvantages. Various measurement methods are discussed in detail by Regan (1972) and Donchin (1969).

Latency. The term latency when applied to components of an evoked potential waveform refers to the time period or time delay between the initial presentation of a given stimulus and the formation of the peak or trough of the positive or negative components (Figure 1). Time of latency is usually measured in milliseconds (msec). Sutton (1969), has identified P1 at a latency of 75 msec, N1 at 100 msec, P2 at 200 msec, N2 at 250 msec, and P300 at a latency of 350 msec.

The reader is cautioned that the stated latencies, as explained by Sutton, are averages and are subject to alteration under different experimental conditions. Sutton, as reported by Price (1974), stated:

> Latency of a component is perhaps the most difficult criterion to apply. We have evidence in our lab that across different experimental conditions as well as across different kinds of

subjects the latency of P300 may be as little as 200 msec or as large as 600 msec.

Topography. A montage in brain wave recording refers to the arrangement used in placing the electrical sensing electrodes in structural relationship to the brain. This electrode arrangement upon the scalp, referred to as a montage, was standardized in 1949 by the Second International Congress in London and published in 1958. It is now referred to as the Ten Twenty Electrode System of the International EEG Federation described by Jasper (1958b), Figure 2 describes the standardized montage.

Topography of brain wave activity, as defined by the EEG Terminology Committee and published by Leeuwen et al. (1966), is the: ". . . distribution of electric activity with respect to anatomical landmarks (p. 308)." Evoked potential waveforms for a given stimulus and sensory modality differ depending upon electrode placement, i.e., anatomical location.

Vaughan (1969) noted that it is essential to define the electrode placement used to record a given waveform phenomena in order to arrive at an understanding of the neurophysiological mechanism and the associated neuropsychological event. Goff et al., (1969), Vaughan (1969, and Vaughan and Ritter (1970) have offered investigative

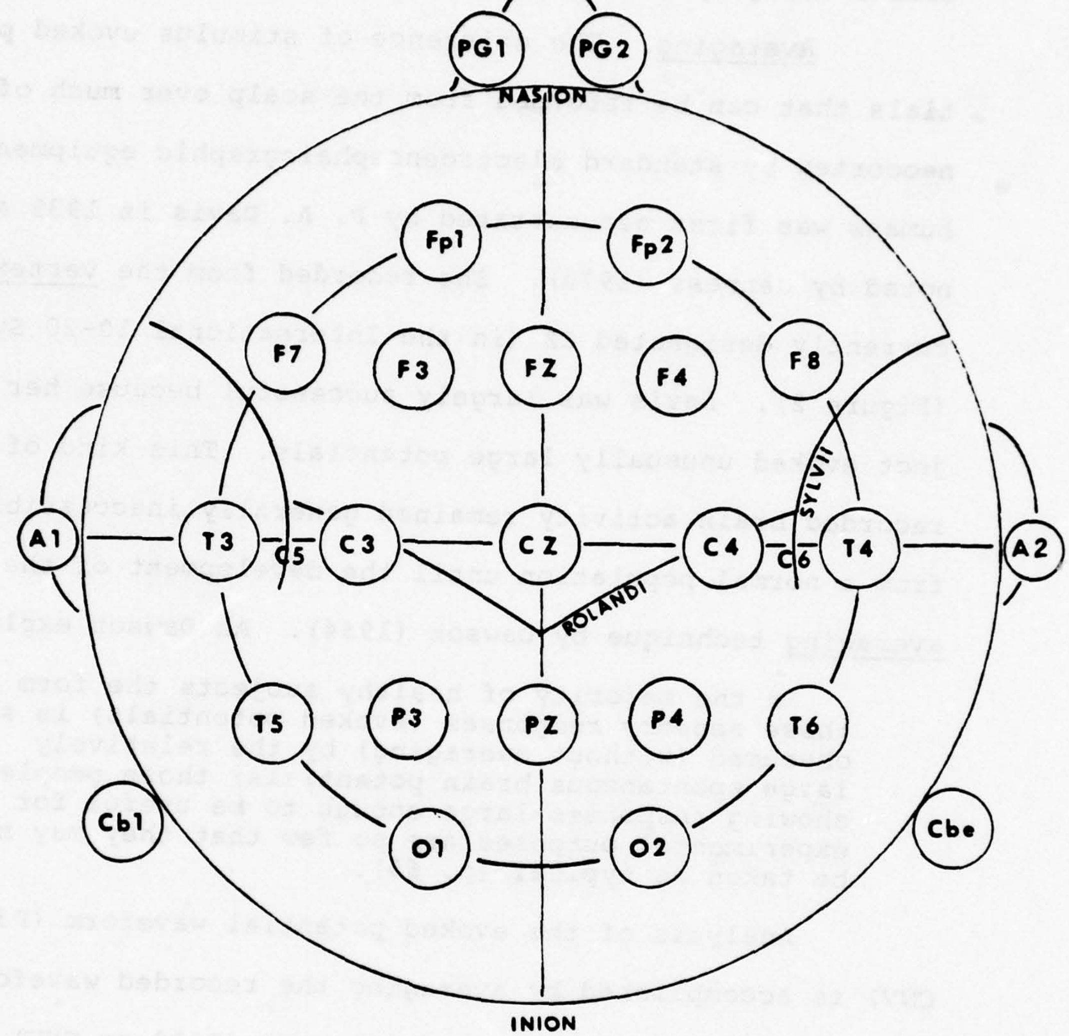


FIG.2 INTERNATIONAL 10-20 ELECTRODE REFERENCE SYSTEM — TOP VIEW

results which relate evoked waveforms to anatomical location of the sensing electrodes. These studies are often termed topographical studies.

Averaging. The existence of stimulus evoked potentials that can be recorded from the scalp over much of the neocortex by standard electroencephalographic equipment in humans was first demonstrated by P. A. Davis in 1939 and noted by Jenness (1970). She recorded from the vertex, currently designated CZ (in the International 10-20 System (Figure 2). Davis was largely successful because her subject evoked unusually large potentials. This kind of scalp recorded brain activity remained generally inaccessible from a normal population until the development of the averaging technique by Dawson (1954). As Dawson explained:

> In the majority of healthy subjects the form of these sensory responses (evoked potentials) is still obscured (without averaging) by the relatively large spontaneous brain potentials; those people showing responses large enough to be useful for experimental purposes are so few that they may not be taken as typical (p. 65).

Analysis of the evoked potential waveform (P300 or CNV) is accomplished by averaging the recorded waveforms in order to separate the wave of interest (P300 or CNV) from the natural, spontaneous, ongoing brain wave rhythms which are regarded as "noise". The signal to noise improvement varies as the square root of the number of presentations of the stimulus.

Walter (1969) recommended recording the evoked CNV waveform for a minimum of 12 trials to achieve a signal to noise ratio 3.45 times clearer than a single primary EEG record. An examination of the literature reveals that a signal to noise ratio ranging from five (25 trials) to nine (50 trials) is customarily used in establishing an average evoked waveform containing a P300 or CNV component. It must be recognized that an averaged evoked potential is an estimate of a population of waveforms as defined statistically.

Nomenclature. Different component labeling systems have been put forth in Ciganek, (1961); Davis et al. (1966); Goff et al. (1962); and Vaughan, (1969). The component labeling system used in this paper follows that of Davis et al. (1966), Friedman et al. (1973), and Wilkenson and Morlock (1967) in designating the components serially, or sequentially, as P1, N1, P2, N2, P300, N3, P4 (please refer to Figure 1). However, the P300 component of interest in this study is additionally referred to in currently published reports as the late positive component and as P300 in recognition of its approximate latency, i.e., peaking at an average of 300 msecs after initial presentation of the stimulus.

Classification of Brain Electrical Activity.

The classification of brain waves is somewhat arbitrary. Electrophysiological brain wave terminologies have not been standardized. A differentiation should be attempted to clarify the understanding of slow waves and slow wave terminologies. The parameters used to measure brain waves are frequency (in cycle per second or Hz), amplitude (in microvolts, uv), and time or period duration (in milliseconds, ms). The frequency range of interest is described by Laidlaw & Stanton, (1966) and Cooper et al., (1969); Delta rhythm (under 4 Hz), Theta rhythm (4 to 7 Hz), Alpha rhythm (8 to 13 Hz), and Beta rhythm (over 13 Hz). These authors use the term slow waves for waves with frequencies under 8 Hz and fast activity for waves over 13 Hz. Other authors, however, use different classifications. Cohen (1969) related the CNV to very slow brain potentials and defines it as an electrical activity slower than the 1 to 4 Hz spectrum.

Frequency as a parameter in describing slow waves become less useful due to low rate of oscillation, hence long periodicity, therefore the time course or duration becomes a primary parameter. The type of equipment utilized to record may be used to differentiate slow waves from faster activity. Alternating current (AC) recorders are applied to measure the faster waves and direct current (DC) recorders used to measure the slower wave activity of the scalp found in the low end of the frequency spectrum.

Overlapping does exist as AC equipment can be used to measure slow waves through utilization of longer time constants (TC). The TC referred to here is that of the capacitive coupling utilized in AC systems to link the amplification device to the transducer. A capacitive coupling is always a resistive-capacitive network (RC) with a finite rate of change of voltage across the capacitance determined by the values of both capacitance and resistance in the circuit. Longer charging times for the capacitance are required to prevent blockage of the slower moving signal in slow wave recording, hence the term "long time constant" coupling.

Cortical steady potential phenomena are reviewed by O'Leary and Goldring (1964), Rowland (1967, 1968), and Adey (1969). The term steady potential refers to the resting potential under passive or nonstimulated conditions of the subject. The human transcortical, brain surface to brain depth, DC value is reported to be 5 to 7 millivolts (O'Leary & Goldring, 1964). This steady potential or resting value is termed the baseline value. When repetitively stimulated, slow waves are evoked, summing temporally to effect baseline shifts which may outlast the stimulating period. These slow aftermaths are termed steady potential shifts. The shift is described by the parameters of polarity (direction of the shift from the baseline, i.e., positive or negative polarity), amplitude (amount of the shift from baseline in micro or millivolts), and time (duration of the shift in milliseconds). Changes in steady potentials have been termed steady potential changes, steady potential shifts, slow wave changes or slow potential shifts. The term Event Related Slow Potentials (ERSP) will be used for the description of waves of the above categories.

Brazier (1963) reported that Caton (1875) observed negative variations in the steady cortical potential of animals in response to sensory stimulations in addition to spontaneous rhythmic oscillations in the electrical activity of the brain unrelated to external stimulation. Kohler and Held (1949) reported existence of long lasting potential changes in the visual cortex in response to visual stimulation. ERSP activity has been observed in response to novel sensory stimuli in other modalities as described by Arduini, Mancia, & Mechelse (1957), and Vanasupa, Goldring, O'Leary, & Winter (1959). Lickey and Fox (1966) investigated ERSP in the visual, auditory and somaesthetic areas of the cat brain. They reported the cortical area associated with a particular modality to be electrically negative when related to responses in other areas. This has been termed the primary negative rule.

Utilizing single and repetitive stimuli, the parameters of slow components of evoked responses have been described in man by Goldring, O'Leary, and King (1958). Sutton et al. (1967) have interpreted these ERSP's to be associated to the perceptual content of the stimulus.

A negative ERSP, termed the Readiness Wave, has been shown by Kornhuber and Deecke (1964) to precede voluntary and passive movements in humans. Gilden, Vaughan and Costa (1966) reported a slow negative shift, termed the pre-motor potential, preceding muscle contraction. The Readiness Wave was subsequently confirmed by Walter (1966b). It was demonstrated that actual physical movement was not required for this ERSP to occur. Caspers (1963) has shown negative ERSP's in association with the orienting reflex and with peripheral stimulation.

ERSP's have been studied in association with conditioning and learning. Morrell (1960) recorded cortical ERSP's to a tone paired with low frequency current. Shvets (1958) measured a negative ERSP that was reported to have accompanied conditioned responses in rabbits. During extinction trials, the ERSP attenuated and disappeared, reappearing during reinforcing trials. Rowland and Goldstone (1963) observed a surface negative ERSP to a click conditioned stimulus paired with a shock. ERSP's disappeared during extinction trials. When appetitive reinforcement was given in place of shock, the subsequent ERSP to the click was positive. This result was confirmed by Marcznski, York and Hackett (1969) who termed the phenomena the contingent positive variation.

In a conditioning paradigm, Walter (1963) used a flash as the conditioned stimulus (CS) and a click as the unconditioned stimulus (UCS) and found that the nonspecific human brain evoked response to the flash was more prolonged in duration, more widely distributed over the cortex, and more prominent than when the flash was presented alone. The nonspecific response to the click became attenuated. The changes in the evoked potentials were even more noticeable when the subject was required to perform a motor response to the UCS. This led Walter to term the phenomena contingent response interaction.

Walter and his associates discovered the CNV during similar paradigmatic experiments when they changed from a short time constant in the capacitive coupling of their recording equipment of 0.3 second to 1.0 second time constant (Walter, 1971). They demonstrated that, when the evoked responses to a single stimulus had habituated (S1), the responses were restored when a second stimulus, S2, was associated with the first, and that the negative ERSP components of the evoked potential to S1 were progressively augmented. They called this negative ERSP the contingent negative variation (CNV) (Walter et al., 1964). Contingent was preferred in place of the narrower term conditioning (Walter, 1971).

CHAPTER III

AN EXPERIMENT CONCERNING ERSP GENESIS AND COGNITIVE ACTIVITY

The author desired to perform an experiment designed to emphasize the aspect of data gathered in the single trial, and to relate this data to the specific response of the subject for that trial. Experimentation that has been reviewed in the preceding chapters has shown that ERSP's are more likely to be developed with meaningful material presented to the subject as a stimulus. The attention given by the subject to the stimulus is also known to have importance in the development of an individual's ERSP's.

Weinberg (1972) and Tecce (1970) have both observed reduction of ERSP amplitude with distraction. They have suggested that "intention to respond" may be related to the development of ERSP's. There are numerous experiments that contribute to the belief that the attentional demands of the experimental situation enhance, to some degree, ERSP development.

In the light of these experiments, it was desired to utilize a stimulus that would demand the consistent attention of the subject to the task and require the expenditure of a high level of processing capacity.

Anagram Solution: A Demanding Task

Verbal problem solving, such as that found in cross-word puzzles or in anagram solution is highly popular as a pastime. The strategies in anagram solution have been studied by many investigators. Dominowski (1968) studied anagram solving as a function of letter moves, Cohen (1968) investigated solution in relation to letter frequency in the language, while Kaplan and Corvellas (1968) investigated word length and its relation to solution time. Mendelsohn and O'Brien (1974) examined difficulty of solution as determined by letter transition probabilities, letter moves and word frequency. A review of these investigations revealed that anagram solution was a demanding task. Mendelsohn (1976) determined that the process of anagram solution entailed the retrieval of words from memory on the basis of letter order cues generated by the subject or present in the anagram itself.

Mayzner and Tresselt's (1965) study and Ronning's (1965) study indicated that five letter anagrams eliminate immediate solutions based upon purely recognition factors. This word length provides sufficient vowel-consonant interactions to extend the number of tenable hypotheses about the solution to make the task demanding. Based upon this data, anagram solution was selected as the cognitive task.

Experimental Design

The experimental design was a Treatment by Treatment by Subjects design. The stimuli to be presented were 5 letter anagrams derived from English language words.

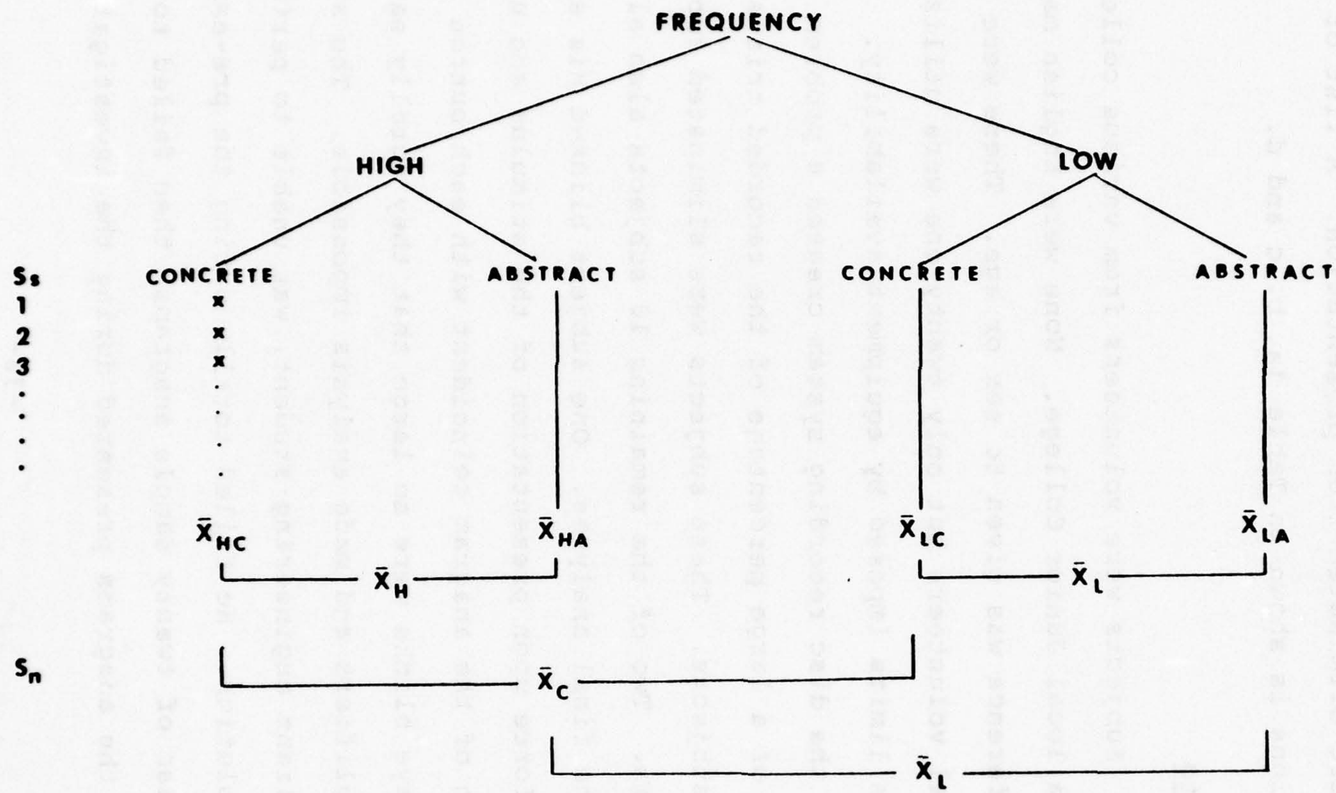
An interest in the solution word retrieval time from memory caused the selection of stimulus words to be made across two dimensions, (1) concreteness versus abstractness and (2) high frequency versus low frequency. Concrete words are those that have a high degree of concurrence of meaning for most individuals. They are usually "object" related, such as HOUSE or WAGON. Abstract words have far less concurrence among individuals as to meaning and may carry affective as well as linguistic meaning. Words such as AGONY or GUILT are in this category. Frequency of words is a measure of their degree of common usage in the language and has been determined by Thorndyke and Lorge (1944).

The basic design for presentation is shown graphically in Figure 12. EEG data was to be recorded for an interval preceding presentation of a stimulus anagram, and to continue for an interval past the indication of a solution, or until the allowed solution time period (30 seconds) expired. Two control conditions were provided. One condition allowed EEG recording during a period when presented with a stimulus word that was easily recognizable but was not an anagram. The second allowed EEG recording during a period when no stimulus was presented and the stimulus display area remained blank. These conditions were randomly interspersed among the anagram presentations and are fully described under the heading of Experimental Procedure.

Three hundred words each of five letters in length were selected by concurrent appearance on lists measuring frequency and concreteness. Seventy-five words each of high frequency/concrete, low frequency/concrete, high frequency/abstract and low frequency/abstract were selected. These words were provided as data to a computer program which printed out the 120 (factorial) possible combinations of the five letters of each word.

This list was then reduced by eliminating those words wherein the rearrangement of the letters could produce more than one word as a solution. From the remaining words, twenty were selected for each word category, a total of eighty words. Five words of each category were selected to be "practice words," the remaining fifteen of each category to be stimulus words. The selection process also reduced those words that contained the letters Q, V, X, Z since Cohen (1968) had found that these letters, due to their low frequency, quickly reduced the available solution hypotheses. Cohen termed these letters "key letters" due to their solution effect.

The selected words were again provided to the computer as data. The program randomly "scrambled" the five



DESIGN FOR 2×2 WITHIN-SUBJECTS FACTORIAL
ANALYSIS OF VARIANCE : 16 SUBJECTS

FIGURE 3

letters in each word of the word list. Several possible lists were generated and inspected for "highly recognizable" letter orders by three members of the research staff working independently. Those orders found to be highly recognizable were eliminated from presentation. A list of final selections is shown in Table 1a, b, c and d.

Subjects

Subjects were volunteers from various college classes at a local Junior College. None were English majors. No preference was given to sex or age. There were thirty original volunteers but only twenty-one were utilized due to time limits imposed by equipment availability. A failure in the disc recording system created a problem in the recall of a large percentage of the recorded trials for three subjects. These subjects were eliminated from the analysis. Two of the remaining 18 subjects also eliminated from the final analyses. One subject blinked his eyes with great force upon presentation of the stimulus and upon resolution of the anagram coincident with each button press. These eye blinks were so large that they totally saturated the amplifiers and made analysis impossible. The second, a brilliant engineering student, was unable to perform anagram solution. He failed totally during the pre-experimental phase of twenty sample anagrams, then failed to solve any of the anagrams presented during the investigative phase.

Stimulus Words and Their Anagrams -

Concrete-Familiar

Word	Anagram
WAGON	GOWNA
CABIN	BIANC
MOUTH	HOMUT
THUMB	HUTMB
JUDGE	DGJEU
MOOSE	EMSOO
STORK	TROSK
APRON	ROPAN
TRAIN	ANRIT
SHARK	RSKAH
RADIO	IDORA
SUGAR	GUARS
BACON	ANCBO
CAMEL	LACME
BANJO	JANOB

Table 1a.

Stimulus Words and Their Anagrams -
Concrete-Unfamiliar

Word	Anagram
FEMUR	MUFRE
VIPER	PIREV
YODEL	OLDEY
QUOIT	UTIQO
FLUKE	KEFUL
BOUGH	OHGUB
DUNCE	NEDUC
VENOM	MENOV
ANVIL	VINLA
DIVAN	VADNI
TOPAZ	ZOTAP
CAMEO	MOCEA
CRONE	ONCRE
COBRA	BACRO
GHOUL	HOLUG

Table 1b.

Stimulus Words and Their Anagrams -
Abstract-Familiar

Word	Anagram
WAGER	GEARW
LOGIC	GLICO
SCOUR	CRUSO
POWER	WEPRO
CRAVE	CAVER
SPITE	ITSEP
DOUBT	TOBDU
BALMY	LAMBY
FAITH	HAFTI
RHYME	HERMY
PAUSE	USAPE
MUSTY	TUMSY
VAGUE	EGVUA
ERUPT	PETUR

Table 1c.

Stimulus Words and Their Anagrams -
Abstract-Unfamiliar

Word	Anagram
JOUST	SOJTU
PIETY	IYTPE
GUILD	IDGLU
FEINT	EFNIT
MINCE	CINME
FOYER	YOREF
LOFTY	FLOYT
GAMUT	MUGTA
FOIST	OFSIT
CLOUT	LUCTO
MOGUL	GUMLO
ATONE	OTEAN
DAUNT	ADNUT
CURIO	RCOIU
FLOUT	TOFUL

Table 1d.

His frustration and discomfort was so apparent before the investigative phase was complete that the run was halted.

Subject Preparation

Each subject was personally interviewed by the experimenter and the equipment and experimental area was explained to the subject. None of the subjects voiced undue apprehension concerning the EEG equipment or the shielded cage in which the subject was to be tested.

Each subject was presented with a typed explanation of the method for conduct of the experiment and questioned for understanding of the experimental process.

Each subject was prepared for EEG recording by cleaning the scalp and skin at the electrode contact areas with a special solution supplied by a local manufacturer of very high quality bio-electrodes. This solution has been found to effectively reduce skin electrode impedance. The skin area was gently cleaned, using a soft brush and the cleaning solution, and the electrodes positioned and checked for security. Four electrodes were placed; a single electrode was placed at the vertex (OZ) of the International Ten-Twenty system. A second was placed at the right mastoid. Two electrodes were placed, one approximately 1.5 cm above and one approximately below the orbit of the right eye. These latter electrodes recorded eye motion and eye blink data. The subject was then seated in the shielding cage, connected to the power supply and optical transmission system and allowed to become acquainted with the response button pressure and range of motion. The subject was instructed to relax and wait while the computers were prepared for the experiment. This provided a 10 minute period of adjustment to the cage and the "feel" of the electrode and associated wiring. The subject was grounded via the left wrist to system ground by a fine silver plate and 16 gauge conductor.

<u>Experimental Procedure</u>

The subject, previously prepared for recording, was seated in an armchair with a wide armrest for the arm and hand to be used for the button response. The chair was inside a shielded cage 40 X 40 inches in area and 84" high. The subject was approximately 24 inches visual distance from a specially prepared plexiglass window containing very fine wire netting that provides continuous electrical shielding without impairing vision through the shielding. A computer graphic display was placed 12" from the shielding window outside the cage. The experimenter's control console was placed out of sight of the subject. All communications were spoken.

Two separate graphic minicomputers were employed in the experiment. These computers were controlled from the experimenter's console and linked through a special control program MESINT. The graphic terminal in the view of the subject displayed the stimulus anagram and eye fixation points, while that at the experimenter's console displayed the real time EEG waves and the eye movements as recorded by the four attached electrodes.

Each subject was asked to close his or her eyes and a one minute baseline recording was performed to test and adjust the amplifiers. The subject was then instructed to prepare to start the experiment. In accordance with the previously presented instructions, a circle of 1/2 inch in diameter appeard in the center of the stimulus display area. The circle moved 4 inches vertically above and below the center at a rate of 1/2 inch per second. The subject followed this movement with his eyes without moving his head. The subject was asked to depress the response switch each time the circle commenced its upward travel. This formed data for basic reaction time. The eye motion and concurrent EEG was recorded on the magnetic media at the experimental console in the form of 128 digitized samples of the analog EEG output per second. This sampling rate was used for all data collection. The results of this exercise was used to determine a coefficient for later artifact removal.

At completion of the eye tracking exercise, the subject was presented with a 1 inch cross indicating the position on the display that would be the center of the stimulus presentation area. The subject was cautioned to avoid unnecessary head movements and eye movements and the first of twenty practice stimuli were presented.

Stimulus Presentation

Stimulus anagrams were all of five letters each 1.5 inches high. The 5 letters occupied 5 inches of display width centered on the display screen. One-quarter second (250 milliseconds) prior to the presentation of the anagram, a two inch by 6 inch rectangle appeared as a signal that the trial was about to commence and indicating the area within which the anagram would be displayed. This provided an eye fixation area for each trial. Upon appearance of the scrambled letter set, the subject attempted to solve the anagram. The response button was to be depressed immediately upon achieving a solution. EEG and eye movement data were recorded from the instant of one second before the appearance of the rectangle and for one second after the response button was depressed.

Practice Trials, Control Trials, and Stimulus

Each subject received twenty practice trials, five of each category. Practice words and anagrams are shown in Table 2a, 2b of each category. Category of presentation was randomly assigned across trials and across subjects under program control, both for the practice and record

Practice Words and Their Anagrams -
Concrete/Familiar-Unfamiliar

Word	Anagram	
TIGER	GRITE	
WATER	EARWT	
CHAIR	CRIHA	Concrete-Familiar
PIANO	ONIPA	
BRAIN	ABNIR	
CUBIT	BICUT	
VIPER	VERPI	
DIVOT	VIDOT	Concrete-Unfamiliar
LIMBO	OIMBL	
DIVAN	VNIDA	

Table 2a.

Practice Words and Their Anagrams -
Abstract/Familiar-Unfamiliar

Word	Anagram	
AGONY	GANYO	
GUILT	IGLUT	
YIELD	EDILY	Abstract-Familiar
HABIT	BAHTI	
BROIL	RIBLO	
SLOTH	LHOTS	
PIOUS	ISUPO	
BOGUS	GUBSO	Abstract-Unfamiliar
FLORA	LOFAR	
AMITY	MIYTA	

Table 2b.

conditions. Two control conditions were also present. Each subject was randomly presented with the letter group TANGO (as in the dance). This was a non-anagram condition and required no solution. The rectangle was also allowed to remain empty or blank after it appeared. The subject had been informed to expect this presentation. A button press was made to each condition upon recognition of the condition by the subject. Approximately 3 seconds after the button press, the subject was asked to respond verbally, either with the solution words, TANGO or BLANK. Knowledge of results was given to the subject only during the practice session.

Upon completion of the practice session, the subject was informed that recording for data would begin and the record trials began. Each subject received a total of 90 stimulus presentations, fifteen each of the 4 categories of anagrams and fifteen each of the TANGO and BLANK conditions. The subject was asked to provide the solution or identify TANGO or BLANK 3 seconds following the button press. The subject said the word aloud and the experimenter recorded the responses by data entry of a numerical code at the control console. If the subject failed to achieve a solution to an anagram within 30 seconds, the display was wiped from the screen, a 10 second period of no display ensued and a new rectangle/word condition followed. The experimenter recorded whether the trial was solved or recognized correctly, incorrectly, or that the subject failed to achieve solution (timed out).

At the completion of the experimental session, the experimenter supplied to each subject a copy of the solved words and the anagram displayed and discussed the reactions of the subject to the experiment and the particular method utilized by each subject to achieve solution. All data was digitized and stored on magnetic media for later analysis by computer.

Data Analysis

The data were transferred from the media records for each subject and stored on magnetic tape at the Engineering Computer Laboratory, University of Southern California. Programs to separate and process data were written in Fortran for execution on a DEC system KL10. All programs were pre-tested to ensure that output would be accurate and reliable.

Two separate analyses of data were performed. An analysis of variance for a treatment by treatment by subject design was performed for the stimulus categories. The independent variables were the treatment categories of (1) Concrete/High frequency anagrams (CH), (2) Concrete/Low frequency (CL), (3) Abstract/High frequency (AH), (4) Abstract/Low frequency (AL), and Subjects (S). The dependent variable was the time required to achieve solution in seconds. Solution time was computed to the nearest 1/128 of a second. The second analysis was performed upon the EEG and eye movement records. This second segment required extensive programming to extract pertinent data from the individual records.

Programming was accomplished to enable the display of individual trials in graphic form. The display was, in effect, a reconstruction of the EEG and eye movement data from the digitized samples. The sample points were plotted on a baseline graph with amplitude in microvolts as the ordinate and time in seconds as the abscissa. The program allowed all waves developed within a single word category to be simultaneously plotted. This produced an "overplot" which allowed a rapid visual "eyeball analysis" of the data. Similarities in the waves for individual trials are seen as a high density of lines at a given amplitude or a similarity in shape at a given latency within the time structure. This method is a form of the superimposition technique described by Regan (1972). Some examples are shown in Figures 4 through 7.

In preparing the graphic plots, the eye movement and blink artifact was algorhythmically removed from the vertex wave. This was accomplished by analyzing the eye track and EEG data for each subject and determining a "removal coefficient" (RC), a number less than 1.0, for eye movement and blink effects appearing as artifact at

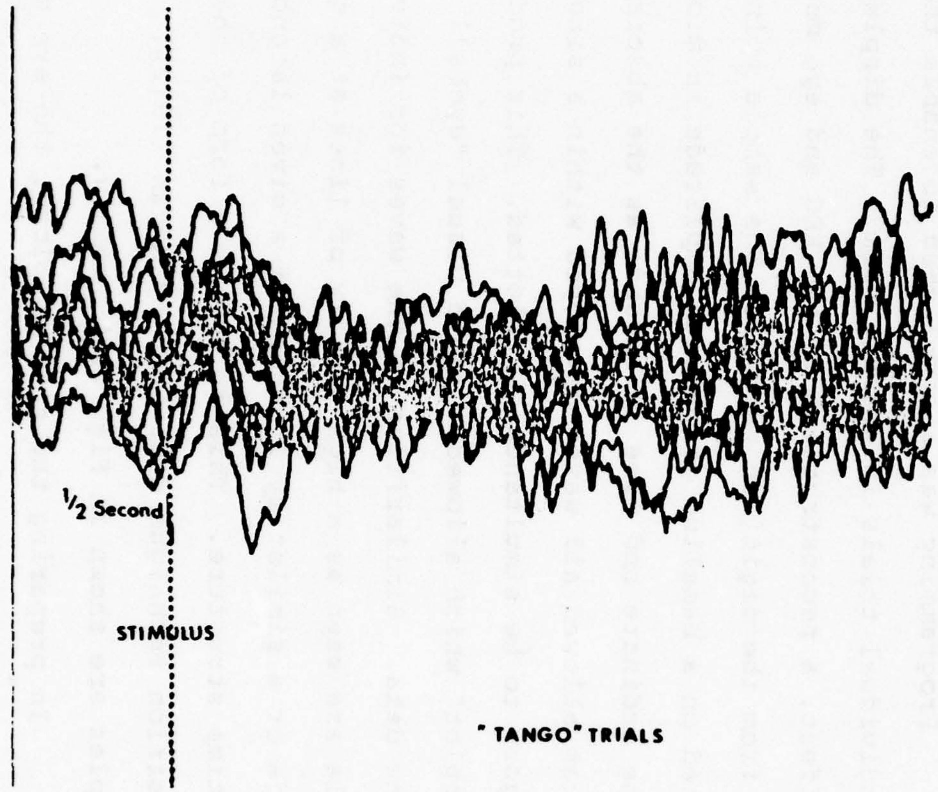


Figure 4. Superimposition of Subject Trials - Example 1

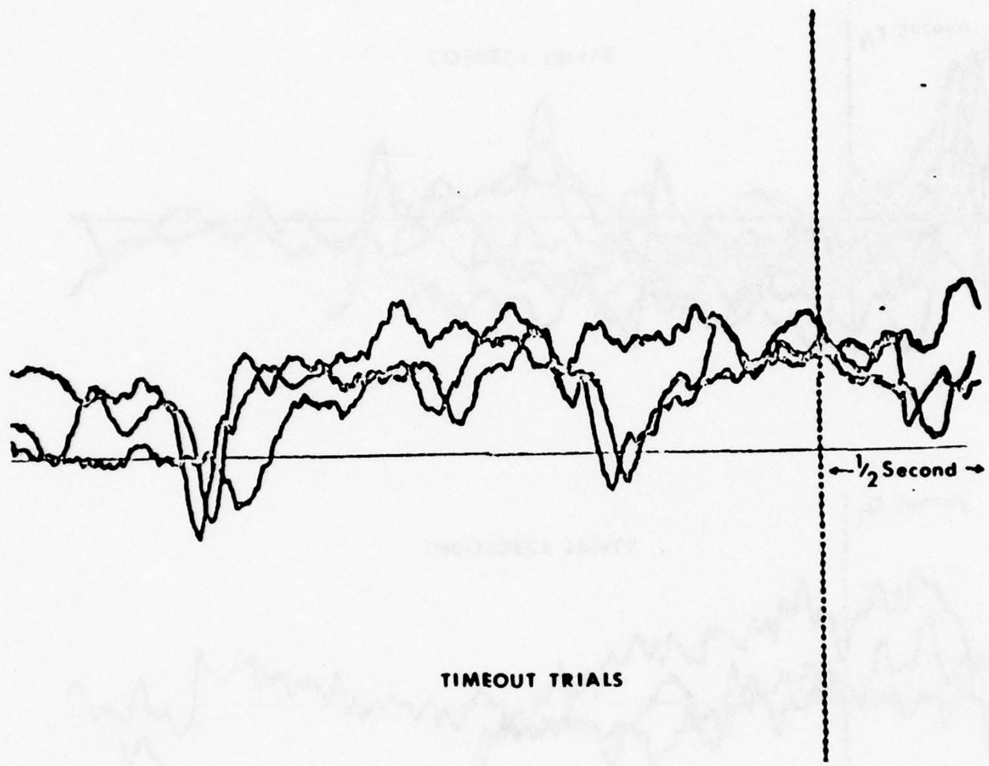


Figure 5. Superimposition of Subject Trials - Example 2

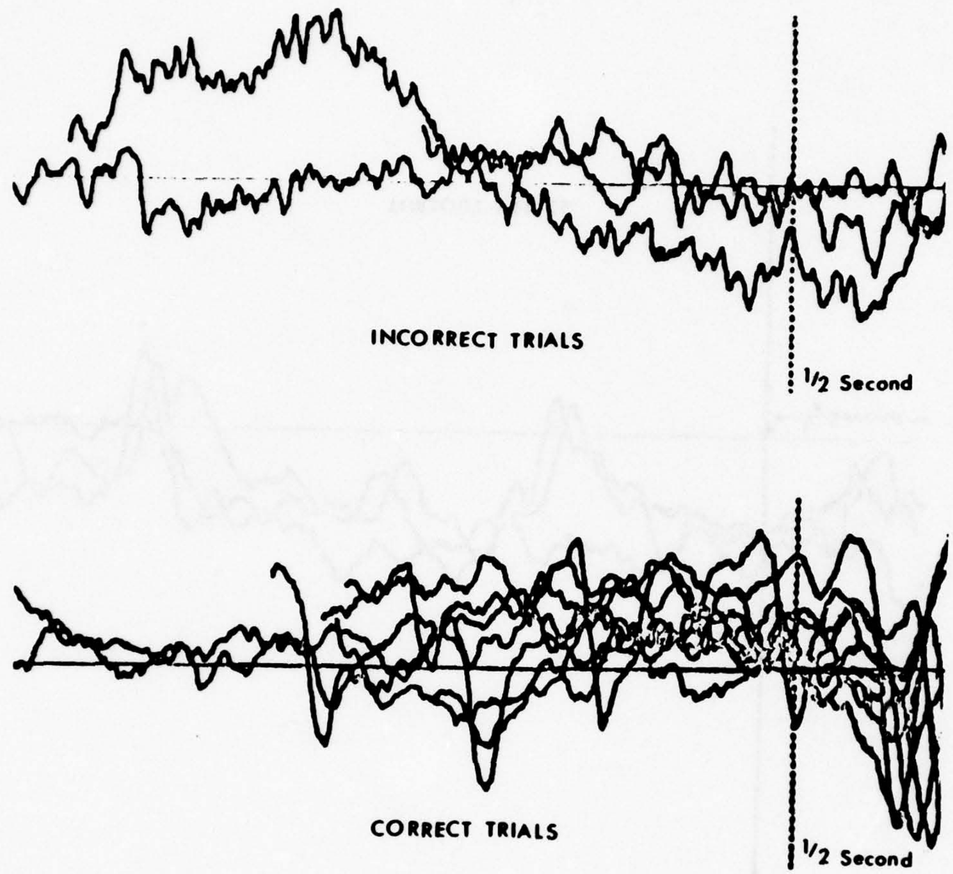


Figure 6. Superimposition of Subject Trials - Example 3

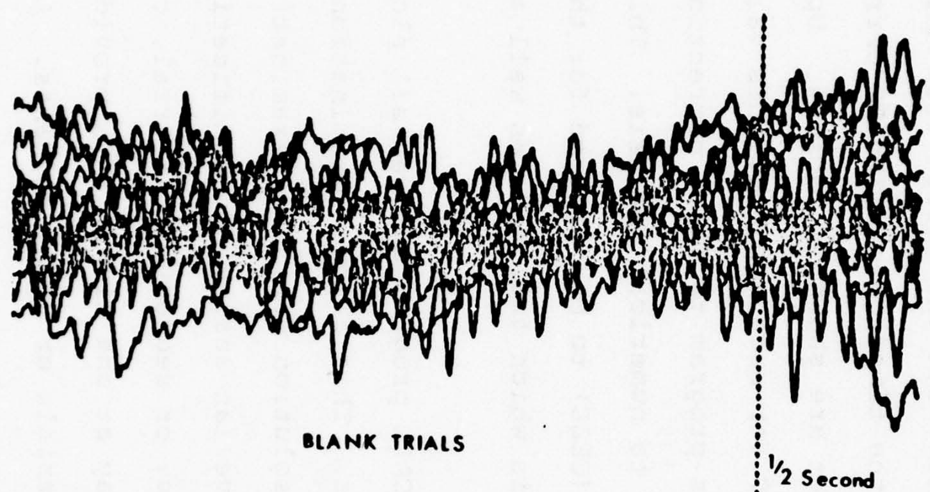


Figure 7. Superimposition of Subject Trials - Example 4

the vertex. This was performed through an interactive graphics program termed RECALL. RECALL allowed plotting of both the EEG data and the eye data upon the screen simultaneously. The RC for the subject was estimated and applied to the EEG. The effect was to multiply the value of the eye movement/blink data at any point in the wave by the RC and subtract the result from the EEG wave at that same point on the time scale. The RC correction values for each subject are shown in Table 3. Upon achieving a satisfactory RC for each subject, this value was provided to the analysis program to allow correction of each EEG for artifact prior to numerical analysis. This provided a corrected EEG (CEEG) to be utilized for the frequency and content analysis which followed, as well as the graphic overplots.

The RECALL program allowed all plotting parameters to be variables. This allowed examination of the entire wave over the solution period or examination of any segment of the wave (an analog of magnification). Up to four separate trials, or segments of a trial, could be plotted upon the display at one time. This provided a rapid visual comparison of trials or trial segments. An interactive mode provided for selection of two points on any wave to be designated for: (1) computation of the elapsed time between the points; (2) the slope of the wave between the two points; (3) the values of amplitude in microvolts for each

Subject	Coefficient
1	.15
2	.18
3	.10
4	.08
5	.12
6	.21
7	.14
8	.11
9	.18
10	.11
11	.19
12	.11
13	.14
14	.17
15	.11
16	.10

Table 3.

Removal Coefficient for Correction for Visual System Artifacts of the two points. A sample of this mode is recreated in Figure 10. Using this mode allowed the investigator to quickly measure latency values for any particular point on the wave relative to any other single point on the wave to the 1/128 of a second.

Waveform Analysis

An analysis of subject data was performed on the DEC system KL-10 at the Engineering Computer Laboratory, University of Southern California. All programs were written in System 10 Fortran. Individual subject data files were transferred to the DEC KL-10 computer and written on magnetic tape. Conversion programs were then written, which reassembled this data into disc files organized in such a way that each trial and eye movement record was written into an array for more direct manipulation.

Two separate analyses of EEG data were performed; a Fourier analysis to determine waveform frequency characteristics, and a Coherence analysis based upon frequency and amplitude at specific frequencies. Fourier analysis methods are discussed in Rabiner and Rader (1972).

The Coherence analysis, or perhaps more properly termed the Cross-Spectral Coherence Analysis, has been described and utilized by Galbraith (1966). Galbraith utilized this method to determine the extent to which the EEG patterns derived from two different brain sites showed similar activity at particular frequencies. Galbraith described a statistic called the <u>Coherence Function</u> defined by equation 1.

$$C(f) = Axy(f) / [\, Ax(f) \cdot Ay(f) \,]^{1/2} \qquad (1)$$

where, $C(f)$ = Coherence at frequency f.

$Axy(f)$ = Cross-spectral density at frequency f

$Ax(f)$ = Auto-spectral density of x at frequency f

$Ay(f)$ = Auto-spectral density of y at frequency f

$C(f)$ is normalized and bounded between 0 (a complete lack of relationship) and 1 (a perfect linear relationship). $C(f)$ is computed for specific frequencies and is not perturbed by activity at other frequencies in the spectrum. Galbraith found that there existed some frequencies in the spectrum that were of very low amplitude and provided a negligible amount of energy to the wave. This might occur as the result of noise patterns in the recording equipment and are often common to all recordings. These frequencies were arbitrarily eliminated from the computation as their contribution was consistently less than a selected value of 10% of maximum amplitude in either the auto-spectral or cross-spectral analysis. A summary statistic of coherence is given in equation 2. This mean coherence function ($\bar{C}$) summarizes the total degree of coherence throughout the analysis epoch across trials of a like type.

The method of computation for $\bar{C}$ is as follows:

$$\bar{C} = \sum_{f_i}[Axy(f_i)C(f_i)] / \sum_{f_i} Axy(f_i) \qquad (2)$$

where $\bar{C}$ = weighted coherence function

$Axy(f_i)$ = Cross-spectral at frequencies (f_i) satisfying the threshold criterion

$C(f_i)$ = Coherence at frequencies satisfying threshold criterion.

$\bar{C}$ is also bounded between Ø and 1.

The utilization of the $\bar{C}$ statistic was described by Galbraith (1967). This investigator assisted Galbraith in several experimental procedures at the University of Southern California (Galbraith and Williams (1972)) and was aware of the value of this measure and its method of computation.

Although the $\bar{C}$ statistic was utilized by Galbraith to relate the frequency specific morphology of EEG epochs derived from different topographical sites, this investigator believed that it was applicable in this experiment. This experiment was attempting to derive similarities or dissimilarities in evoked waveforms under differing conditions inherent in the stimulus. The review of literature had revealed several investigations which related the occurrence of the CNV and/or the P300 to information processing characteristics of the stimulus or presentation conditions. The experimental design described for this investigation holds presentation conditions constant and varies only the inherent characteristics of the stimulus.

Variations in the ERSP should then represent the individual's information processing characteristics. Since individual trials are being compared within each subject, the tendency to smear trial by trial differences seen in averaging methods should be eliminated.

Computation for the $\bar{C}$ statistic provides frequency specific data and amplitude data for each trial of the analysis. This data is collected and graphically plotted to allow the $\bar{C}$ statistic to be related to specific patterns of frequency found for each trial. The frequency graphs for each subject are contained in Appendix B, Figures B1 through B16. The mathematical and statistical bases for deriving the Fourier components and their utilization in coherence analysis are described in Blackman and Tukey (1958), Walter, D.O. (1963), and Walter and Adey (1965).

Results

ANOVA for Stimulus Dimension. The analysis of variance of solution time for the Concrete-Abstract and High-Low frequency dimension is shown in Table 5. The data from which the ANOVA was derived is shown in Table 6. This data is for those trials in which the subject correctly solved the stimulus anagram. Trials in which the subject responded with an incorrect solution or failed to solve the anagram within the maximum time limit of 30 seconds are excluded. All values in Table 4 are solution times averaged

Concrete/Fam	Concrete/Ufam	Abstract/Fam	Abstract/Ufam	Tango
3.673	3.146	4.754	5.164	.643
3.756	11.638	15.042	11.059	.898
10.354	11.444	7.830	14.448	1.296
5.958	5.418	7.112	14.369	.990
8.792	16.058	11.680	20.098	1.502
14.105	9.130	13.380	16.522	2.601
13.378	8.566	10.051	13.632	1.446
8.578	10.637	8.200	12.947	.948
4.023	3.443	5.146	5.280	.844
5.896	12.369	14.354	11.234	.719
11.178	11.077	8.686	13.160	1.326
7.036	6.877	7.931	13.649	.873
9.656	16.399	12.676	17.355	1.342
14.488	9.665	12.941	16.178	2.550
12.700	9.354	11.014	12.815	1.501
9.228	11.866	8.877	11.563	.926
$\overline{X}$ = 8.925	$\overline{X}$ = 9.812	$\overline{X}$ = 9.80	$\overline{X}$ = 13.093	$\overline{X}$ = 1.275
SD = 3.648	SD = 3.80	SD = 3.163	SD = 3.886	SD = .579

Table 4.

MEAN RESPONSE TIMES
ANAGRAM SOLUTION

Source	ss	df	ms	F	p
TOTAL	948.518	63	-		
Subjects	509.637	15	-		
Concreteness	74.643	1	74.643	23.253	$<.001$
Familiarity	64.886	1	64.886	10.204	$<.01$
Concreteness x Familiarity	18.863	1	18.863	2.06	$<.75$
Error Concreteness	48.215	15	3.21		
Error Familiarity	95.389	15	6.359		
Error Concreteness x Familiarity	136.885	15	9.162		

Table 5.

ANALYSIS OF VARIANCE: SOLUTION TIME FOR ANAGRAMS

(TREATMENT-BY-TREATMENT-BY-SUBJECTS DESIGN) across correct trials within the subject and each of the stimulus dimensions. The fifth set of entries are the average response times per subject for the word recognition task (TANGO) and are shown for information only, since they were not considered in the analysis of variances.

The results of the Analysis of Variance for the stimulus dimensions showed a highly significant effect upon solution time for the Concrete-Abstract dimension ($F=23.25$, $p < .001$). The High-Low frequency dimension was also significant ($F=10.20$, $p < .01$) but to a lesser degree than that of concreteness. The test for interaction effects failed to reach significance ($F=2.06$, $p < .75$).

Analysis of Coherence. The C value was determined through a Fortran program running at the Engineering Computer Laboratory at USC. The program was tested for running time and a determination was made that evaluating C for every trial would utilize nearly 240 hours of Central Processor time. The cost of such a complete analysis was prohibitive. A complete analysis requires the computation of 8100 C values per subject (90 trials X 90 trials). The inordinately expensive analysis could be reduced to a reasonable cost by evaluating only a subset of trials. The method chosen was to randomly select two (2) correct and two (2) incorrect trials from each anagram grouping. Additionally, two (2) trials were randomly drawn from the "TANGO" and "BLANK" presentations for each subject.

A C value was computed for each selected trial against all other trials and these values printed out in matrix form. The major diagonal of the matrix consisted of the auto-correlation function of each trial. A mean value ($\bar{C}$) was then determined for each trial group. This produced a series of matrices, one for each subject shown in Appendix A, Tables A1 through A16. The cell values represent the mean coherence, $\bar{C}$, determined for each type of response e.g. Correct (CMEAN), Incorrect (IMEAN), Time-out (TMEAN), TANGO (GMEAN), and BLANK (BMEAN). These values were averaged and subjected to a One-Way Analysis of Variance (Table 8). The result was highly significant ($F=257.2$, $p < .0001$), and are shown in Table 6. The $\bar{C}$ values were then averaged across subjects and analyzed for differences among means by a Scheffe Paired Comparisons test. The results of that test are shown in Table 7. The Scheffe Critical F value for the test was 20.41. Comparison I tested for a difference in coherence means of the correct trials against all other trials excluding the TANGO trials. The result was highly significant ($F=151.5$, $p < .001$).

Comparison II tested only for differences between the mean coherence values for the correct and TANGO trials. The result failed to reach significance ($F=4.35$). Comparison III tested for differences between mean coherence values of the Time-out and Incorrect trials. This comparison

Source	ss	df	ms	F	p
TOTAL	395.246	79	-		
Subjects	12.359	15			
Mean Coherence	380.645	4	95.16	2571.89	$p < .001$
Error	2.242	60	.037		

Table 6.

ANALYSIS OF VARIANCE: 5 MAJOR VALUES OF $\bar{C}$
(ONE WAY DESIGN)

Scheffe Critical F = 20.41

		Correct	Incorrect	Timeout	Tango	Blank	
	$\bar{A}$	8.532	5.866	5.107	7.677	2.284	Result
TEST	I	+3	-1	-1	0	-1	F=151.5
	II	+1	0	0	-1	0	F=4.35
	III	0	+1	-1	0	0	F=3.428
	IV	0	-1	-1	+2	0	F=57.29

Table 7.

SCHEFFE TEST OF PAIRED COMPARISONS

failed to reach significance also. The final test, Comparison IV tested for differences between the mean coherence values of Incorrect, Time-out, and TANGO trials. This result was significant ($F=57.29$, $p < .01$). The final result of these comparisons of mean coherence values found the correct trials significantly different from all others except the TANGO trials. Correct and TANGO trials were found to be quite similar.

Discussion

The Stimulus

The results of analysis of the time to solve an anagram reveals interesting aspects. Some comments about the task and individual subject differences are of value. An examination of the subjects'correct solutions for the word list revealed that no particular word or word group was solved more often than others. However, the number of failures to solve the anagram was high across all subjects. All subjects indicated that the task was difficult. There was some tendency for the subjects to separate into two groups along some tenuous line of verbal fluency. Those with verbal fluency, as indicated by post-test discussion, were characterized by stating that they were not uncomfortable with verbal tasks, often worked on crossword puzzles, and were less apprehensive with writing tasks. Those less verbally fluent indicated that they avoided or were more apprehensive where verbal demands were high. All subjects were achieving higher than average grades in college courses. The effect of the stimulus dimensions were surprising, specifically in that the familiarity effect was much smaller than that of abstractness, and further that these dimensions created no significant interaction.

The lesser effect of familiarity might be accounted for by the general educational level of the subjects. All were college students and perhaps have gained a greater usage of the words in the stimulus list than might be found in larger, more varied populations.

Each subject was questioned as to the method utilized in solving the stimulus anagrams. Most found it difficult to describe with exactness, but in general there was a process of "mental rearrangement" of the letter order indicated. This rearrangement was usually not a simple reordering, but based upon an unspecifiable linguistic knowledge of natural pairings of letters. These natural transitional probabilities appear to be intuitively known and derived from linguistic experience rather than studied knowledge. For example, in the anagram <u>RCAIH</u>, <u>CH</u> would have a high transitional probability and become an immediate unit of rearrangement. Without exception, subjects stated that they need not completely rearrange all letters before <u>recognition</u> as a word took place. Often, after one or another arrangement was made, the word "popped" into sudden recognition. This would tend to support the concept that some internal template matching process was in effect.

Solso, Topper and Macey (1973) demonstrated that bigram frequency and bigram versatility affect anagram solution times. Bigram frequency is based on the probability of two letters appearing together in the language, while versatility is measured by the number of words in the language in which a particular bigram may appear.

It is possible then to postulate a multi-stage process for anagram solutions. The subject utilizes experientially determined knowledge of transitional probabilities to form linguistic units such as bigrams (or even trigrams). A search process is commenced in memory to match this unit to words in which this unit is found. The bigram of greater versatility would result in a longer search list. Paivio (1963, 1965), Miller, Galanter, and Pribram (1960), Smith and Noble (1965), and many more recent findings, indicate that concrete words, because of their consistent association with specific objects or events, are particularly effective in arousing imagery. Imagery, in turn has been shown by many researchers to mediate associative memory and recall in many learning situations. It is proposed that concrete words also have primacy in the search list and are therefore matched more quickly than the abstract (and consequently low imagery) words.

Familiarity and usage frequency would also affect primacy, but those words of high imagery, even if less frequently utilized, would be more potent for recall and matching. Paivio, Yuille, and Rogers (1969) noted a stronger effect for imagery over meaningfulness in associative recall experiments. Craik and Tulving (1975) studied depth of processing and retention for words, stating "memory performance is enhanced to the extent that the encoding question or context forms an integrated unit with the target word . . . . and thus yields better memory performance, first, because a more elaborate trace is laid down and, second, because richer encoding implies greater compatibility with the structure, rules, and organization of semantic memory. This structure, in turn, is drawn upon to facilitate retrieval processes." (p. 291-292)

Imagery necessitates a great deal of elaboration and integration, yet it is conservative of process steps. Images are formed as wholes, yet have a nearly infinite capacity for further integration and elaboration, thus in Craik and Tulving's sense, they (images) facilitate retrieval.

The ERSP

The second, but primary portion of this experiment was the recording of the EEG and ERSP's of the subjects during the anagram solution process.

To recapitulate, the subject was presented with a 5 letter anagram of a stimulus word of one of four categories, a non-anagram recognition word (TANGO), as a blank screen. All presentations were preceded by the appearance of a rectangular viewing box in which the stimulus would appear. The rectangle served as 1) a preparatory signal and 2) an eye fixation point. EEG data was recorded for one second pre-stimulus and post-response.

It was noted in the preceding section concerning the solution to anagrams that the subjects found the task generally difficult. As a result, the average solution times were of about 8 to 16 seconds. The results of the coherence analysis found that the correct trials, where the subject solved the anagram correctly, and the recognition trials, where the subject identified the word TANGO, were highly similar in the segment analyzed. Other trials, where an incorrect solution was perceived, the subject failed to form a conclusion (timed-out), or received only a blank screen, were not sufficiently coherent to correct or TANGO, or to each other, to be significant. This was demonstrated by the Scheffe Paired Comparisons analysis.

Before commenting directly upon these results, let us again examine the subjects activities and the initial methods of analysis of the neurophysiological records. The subject, upon perceiving a solution to the anagram, pressed a microswitch indicating solution. After recording data for one second, the experimenter asked the subject to say the word solution aloud. Notes taken by the experimenter during the recording session are of interest to the results.

When the subject achieved a correct solution, the vocal response was precise and uttered as a statement. When the subject was in error, the response was usually uttered as a question. This tendency was noted by an assistant while recording early validation subjects and initiated the note taking. Only on two occasions was the error stated with the same apparent certainty as a correct response. In both cases the error was very similar to the correct solution (QUOTE vice QUOIT and FIRST vice FOIST). The subjects failed to achieve a solution (timed-out) in many more cases than they achieved an erroneous solution. In several subjects, the error rate was so low that the analysis matrix had to be filled with empty cells since there were insufficient errors to completely supply the cross-correlation matrix. A visual analysis was initially performed by superimposing the responses that fell into a word type and response category. For superimposition purposes, the trial was broken into halves, the first half anchored at the presentation time, the second half anchored at the response time. This forced the presentation and response segments into congruence despite actual trial length. Figure 16 is an example of a superimposition display for correct trials. Where the superimposition is highly similar, the display converges one trial with another. Where the superimposition is dissimilar from one trial to the next, the display is a chaotic jumble of lines.

The length of trial precluded the possibility of obtaining a classical CNV wave. There did appear to be a general move toward negativity within 300-500 milliseconds following the presentation of the stimulus word. In some subjects this negativity was pronounced and at times achieved nearly 30 microvolts, but varied in amplitude both within and across trials. This negative drift, which generally resembles the CNV in morphology, would persist for 800-1000 milliseconds, plunge suddenly positive for 100-200 milliseconds and return to the negative again. The shape of the negative limb was inconsistent, as was the amplitude of the negative as well as the positive excursion. In 4 subjects the wave remained negative for the entire duration of the anagram trials, with "dips" toward positivity within a somewhat longer timespan than the average, about 1500 milliseconds. The "dip" occasionally crossed the baseline but only to an average of 8-10 microvolts, then returned to the negative side, achieving an average of 20 microvolts negative.

During BLANK trials for most subjects the wave took on the more transient characteristics of a normal EEG with larger waves in the theta (5-7 hz) or low alpha (8-10 hz) becoming characteristic. This data is shown in the subject frequency profiles Appendix B, B1-B16.

The area of greatest interest is in the one second period following the motor response for both the correct and TANGO trials. It is here that a highly congruent activity is seen that is substantiated by the coherence analysis and the frequency spectrum (Appendix B). At a latency of about 200 milliseconds following the motor response the wave falls suddenly positive reaching maximum positivity at an average of 250 milliseconds. This maximum positivity varied both within and across subjects, in both latency and amplitude, for both the correct and TANGO trials. The positivity was more consistent in both amplitude and latency for TANGO trials than for the anagram trials. A mean response time for button pressing had been established for each subject during the practice and stabilization period. This time varied across subjects from 45 milliseconds to 75 milliseconds and was markedly consistent within each subject (Table 8.) Adding this time to the latency of maximum positivity, a latency from time of achievement of solution may be estimated at 300-400 milliseconds with a mean of 350 milliseconds. This latency is consistent with other research findings of the occurrence of a P300 wave. This research is reviewed in Chapter IV.

Walter (1968) had noted that with long interstimulus intervals of 8-10 seconds the CNV (where formed) appeared as a series of individual segmented waves. Walter and Cohen (1969) had noted the positive swing of the CNV after recognition of a stimulus requiring interpretation. This Positive After Effect (PAE) was later to become the P300. The stimulus conditions of the present experiment provide the opportunity for a similar development. The negativity noted and discussed earlier is believed to be similar to a segmented CNV as described by Walter. The onset of the stimulus becomes the initial or warning stimulus (S1) for the subject. The imperative stimulus is a

Subject	Mean Responses Time	SD
1	51.5 ms	7.5
2	60.0 ms	14.5
3	67.8 ms	7.5
4	75.0 ms	12.5
5	48.5 ms	7.5
6	84.0 ms	9.3
7	62.5 ms	11.5
8	70.2 ms	13.5
9	45.0 ms	8.5
10	90.0 ms	15.0
11	78.5 ms	7.5
12	62.3 ms	8.3
13	73.5 ms	13.0
14	54.0 ms	7.5
15	61.0 ms	16.5
16	53.6 ms	9.5

Table 8.

Subject Basic Reaction Times for Button Pressing self generated stimulus (S2) upon recognition or anagram solution. This, in turn, is followed by a motor response and a PAE or P300.

Slow Potentials: Indicators of Input/Output Processes.

A major difficulty in determining the behavioral correlates of ERSP generation may be found in the wide variety of paradigms employed. Each different paradigm tends to emphasize one specific aspect of behavior. Thus we find expectancy, conation, decision-making, or contingency being applied as explanatory constructs and particular experiments performed to illuminate that one behavioral element.

Tecce (1970, 1972) saw the CNV particularly in a relationship to attention. His experiments in distraction effectively demonstrated the diminution or elimination of the CNV under distracting or divided attention conditions. Tecce did not attempt to provide a theory of attention or attentional mechanisms in which slow potential shifts could be directly related to system processes of the Central Nervous System (CNS).

Routtenberg (1972) published a theory at about the same time that Tecce was performing his early experiments. This Input-Output Reciprocity Theory is discussed in Chapter II. The theory is a psychobiological concept concerning memory storage/retrieval mechanisms, but because of the _systems_ considerations is more holistic than most process theories.

It is the nature of psychological research to focus upon specific behavioral elements, thus fragmenting the behavioral process as well as the individual system that is the subject of the investigation. The intent of this fragmentation is the achievement of a clear, concise specification of an element with the full intent of restructuring and integration at some later time. While reviewing nearly two decades of literature, seldom has an attempt at integration of knowledge about system elements been identified. Routtenberg has attempted one such integration.

Routtenberg derived his theory as an extension of studies into the sleep-wakefullness cycle. It was the recognition of the system relationships inherent in this cycle and the integrated operations of limbic, hippocampal and reticular sub-systems that produced its extension. Routtenberg, in formulating his integrative theory of memory, postulates that the _memory system_ is in constant operation, but that one cannot input to and output from the system at the same instant. He perceives the memory system as integrated into the overall mechanisms of data processing. Memory is not just a repository for knowledge, but the central storage for operational programs that produce the entire repertoire of activity. In this system, one may unify concepts of readiness to respond, expectation, or conation as either emitted (self-generated) or elicited (externally cued) activities of a data handling system. Attention, particularly selective attention, is a subsystem response to narrow the input operation and effectively gate data handling processes which have limits to their capacity. Routtenberg views the hippocampus as a gating mechanism or controller and the presence or absence of hippocampal theta as an indicant of dominance of either the input or output system. The activity of the hippocampus is in turn related to cortical D.C. shifts or the presence of slow waves. These are in turn related to selective attention or selective responding operations which are necessary to complete the data handling cycle of operations.

Anagram Solution: Selective Attention and Selective Responding.

The task, noted as difficult by the subjects, required a high level of attention or concentration. Picton and Low (1971) demonstrated the maintenance of the negativity wave past the motor response period, particularly where the task was engaging, difficult, and resolved only by a feedback signal occurring two seconds past the motor response point.

The trials in which the subject fails to resolve the anagram maintains the general level of negativity as long as the subject is engaged with attempting solution.

Only in those trials where solution is achieved by recognition of the true stimulus word is there evidence of the sudden positive swing, recognized as the P300.

Squires, et al. (1975) investigated ERSP's (P300) evoked during an auditory signal detection task.

Previous investigations had agreed that a P300 was present with correct detections of a signal (hits) but absent with misses, false alarms, and correct rejections. The then current concepts of P300 genesis indicated that similar cognitive operations were present in these remaining responses, and should evoke a P300.

The result of the Squires et al. experimentation was the demonstration of a P300 for hits, false alarms, or correct rejections, all of equally large amplitude if the decision about the outcome was made with a <u>high degree of confidence</u>.

Most of the paradigms for the measurement of ERSP's are attentionally demanding. It is possible, utilizing Routtenberg's theory to relate the appearance of slow potential shifts such as the CNV or P300 to self-directed spontaneous brain activity subserving facilitory/inhibitory mechanisms for input/output processing. These processes require selective attention and responding, which are controlled by (as yet undefined) action upon the cortex, Reticular Activating System, the hippocampus, and limbic systems.

Although an exhaustive exposition of the Routtenberg theory is not possible here, there appears to be a high degree of "goodness of fit" to the operations and ERSP responses reviewed and experimentally derived.

Conclusions

In this experiment, the difficult task demanded a high degree of selective attention, initiated by the onset of the display rectangle. A general shift toward negativity ensued as part of the process of attending, processing data, and preparing to respond. In some subjects, this negativity was segmented, and interspersed with short duration, low amplitude positive swings. This segmented wave was not completely consistent across subjects, indicating different internal, idiosyncratic aspects of processing for individuals. Less segmentation perhaps indicates a more consistent selective attention, but this is not supported by particular performance efficiency. Correct responses and TANGO responses resulted in the development of a positive wave of about 350 milliseconds latency after the estimated solution time. This wave is believed to be the ERSP termed P300. This ERSP was not seen in BLANK, time-out, or incorrect trials. The existence of the P300 in the correct response and TANGO conditions is supported by the high coherence between these trials. The failure of the P300 to appear in incorrect, time-out and BLANK trials is supported by the low coherence of these trials with the correct and TANGO trials and with each other. The frequency spectral analysis for subjects (Appendix B) demonstrates a low frequency wave of about 2/3 hz in the correct and TANGO trials that is not evident in the others. This low frequency element is consistent with the description of a P300 in literature. The appearance of a P300 in Correct and TANGO trials is considered to be the result of an internally mediated release from processing and release of selective attention to the task and responding. This shift in attention/processing is emitted due to positive recognition that a trial is complete. BLANK trials require no processing or attention and are characterized by Theta and low Alpha activity often associated with low attention. Time-out trials show the negative shift but no P300. Further recording past the end of the timed period might have demonstrated some release of attention but this is only speculative. Incorrectly perceived solutions were seldom conveyed as confident solutions, therefore, a high amplitude P300 was not developed, since the subject maintains a degree of engagement which is reflected in the "questioning" type of response. There is some indication of a very low amplitude P300 type wave present at about the proper latency in <u>incorrect</u> trials. These were not detected by the frequency analysis.

The following conclusions are drawn from the foregoing experiment and its relation to the reviewed literature.

1. Slow potential shifts, negative and positive nature, may be elicited in demanding tasks where high information processing and selective attention is required.
2. The morphological character of the elicited wave is highly individualized and, to a degree, represents the processing parameters of the neural system engaged.
3. Negative wave genesis is related to engagement of <u>selective attention</u> and <u>selective responding</u>. This is supported by Tecce (1972) who has demonstrated reduction of the negative shift by intrusive activity.
4. The positive shift called the Positive After Effect or P300 is an indicant of release or shift in attention and processing, and is <u>emitted</u>, or under internal control. This is in congruence with reviewed research exemplified by Squires, et al. (1975) where subjective certainty of task completion allowed selective attending to be released, allowing the system to return to less narrow operation.

5. The negative/positive wave complexes are not causal, but may represent the shift of the processing mechanism from one operational mode to another.
6. The Routtenberg model of input/output reciprocity, although not exhaustive, provides an excellent conceptual basis for the elucidation of memory and attention processes, their underlying biological and neuroelectrical properties and interactions.
7. The relationship of ERSP and D.C. potential shifts to the Routtenberg model is further supported by Walter (1968), who noted that CNV genesis is under "social" control. A subject when instructed not to attend or respond to a trial produces no CNV. This is in congruence with the endogenous aspects of the Routtenberg model concerning emitted control of attending or responding.

In a retrospective view of the many investigations summarized, and considering many that were reviewed but not included, the power of the Routtenberg model to relate ERSP's to attentional or responding operations increases. It is realized that this model or theory is far from complete. Much research will be required to either enhance or diminish the theory's fit to results and paradigmatic conditions. It appears that the Routtenberg theory is not well known, for little has been done to test its implications. This author believes sincerely that the investigative effort to reveal the nature and relationships of the activity of the Central Nervous System and observable behavior requires a more integrated approach. Perhaps this theory, or another, will provide this integration.

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Recent Major Psychoneurological Discoveries

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Signal Analysis

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APPENDIX A

Subject Mean Coherence Matrices

Subject 1 through Subject 16

1

	CMEAN	IMEAN	TMEAN	GMEAN	BMEAN
CMEAN	.912 SD.056	.649 SD.055	.569 SD.054	.800 SD.053	.299 SD.059
IMEAN		.875 SD.052	.675 SD.056	.524 SD.054	.454 SD.066
TMEAN			.808 SD.053	.630 SD.052	.414 SD.063
GMEAN				.918 SD.000	.327 SD.052
BMEAN					.766 SD.000

2

	CMEAN	IMEAN	TMEAN	GMEAN	BMEAN
CMEAN	.833 SD.063	.564 SD.056	.488 SD.051	.726 SD.058	.191 SD.054
IMEAN		.823 SD.035	.591 SD.049	.403 SD.069	.384 SD.063
TMEAN			.733 SD.053	.542 SD.052	.328 SD.054
GMEAN				.917 SD.000	.199 SD.049
BMEAN					.518 SD.000

3

	CMEAN	IMEAN	TMEAN	GMEAN	BMEAN
CMEAN	.884 SD.061	.621 SD.059	.541 SD.061	.805 SD.060	.256 SD.051
IMEAN		.823 SD.054	.646 SD.061	.473 SD.050	.417 SD.047
TMEAN			.770 SD.061	.578 SD.065	.347 SD.054
GMEAN				.912 SD.000	.257 SD.033
BMEAN					.573 SD.000

4

	CMEAN	IMEAN	TMEAN	GMEAN	BMEAN
CMEAN	.908 SD.055	.642 SD.071	.560 SD.053	.846 SD.046	.277 SD.067
IMEAN		.800 SD.000	.650 SD.058	.518 SD.044	.461 SD.053
TMEAN			.794 SD.060	.592 SD.055	.374 SD.063
GMEAN				.950 SD.000	.291 SD.033
BMEAN					.700 SD.000

5

	CMEAN	IMEAN	TMEAN	GMEAN	BMEAN
CMEAN	.826 SD.051	.571 SD.056	.487 SD.052	.786 SD.063	.204 SD.057
IMEAN		.783 SD.052	.588 SD.054	.451 SD.064	.345 SD.063
TMEAN			.733 SD.058	.552 SD.051	.313 SD.055
GMEAN				.880 SD.000	.242 SD.053
BMEAN					.710 SD.000

6

	CMEAN	IMEAN	TMEAN	GMEAN	BMEAN
CMEAN	.825 SD.054	.574 SD.054	.487 SD.059	.756 SD.055	.189 SD.057
IMEAN		.754 SD.050	.576 SD.057	.439 SD.045	.349 SD.056
TMEAN			.721 SD.055	.504 SD.056	.318 SD.067
GMEAN				.886 SD.000	.286 SD.041
BMEAN					.628 SD.000

7

	CMEAN	IMEAN	TMEAN	GMEAN	BMEAN
CMEAN	.933 SD.046	.681 SD.041	.582 SD.062	.844 SD.052	.318 SD.052
IMEAN		.000 SD.000	.699 SD.054	.532 SD.071	.500 SD.098
TMEAN			.829 SD.057	.627 SD.058	.409 SD.045
GMEAN				.972 SD.000	.290 SD.027
BMEAN					.665 SD.000

8

	CMEAN	IMEAN	TMEAN	GMEAN	BMEAN
CMEAN	.792 SD.057	.531 SD.058	.468 SD.054	.712 SD.049	.175 SD.058
IMEAN		.723 SD.062	.581 SD.054	.384 SD.024	.316 SD.072
TMEAN			.702 SD.055	.500 SD.065	.298 SD.067
GMEAN				.825 SD.000	.191 SD.047
BMEAN					.588 SD.000

9

	CMEAN	IMEAN	TMEAN	GMEAN	BMEAN
CMEAN	.798 SD.051	.544 SD.054	.472 SD.059	.725 SD.073	.212 SD.060
IMEAN		.746 SD.053	.582 SD.061	.425 SD.047	.371 SD.057
TMEAN			.725 SD.053	.521 SD.055	.296 SD.071
GMEAN				.892 SD.000	.231 SD.066
BMEAN					.588 SD.000

10

	CMEAN	IMEAN	TMEAN	GMEAN	BMEAN
CMEAN	.907 SD.047	.629 SD.059	.553 SD.058	.812 SD.052	.272 SD.063
IMEAN		.849 SD.058	.683 SD.051	.506 SD.078	.434 SD.066
TMEAN			.806 SD.053	.569 SD.058	.371 SD.056
GMEAN				.919 SD.000	.328 SD.026
BMEAN					.754 SD.000

11

	CMEAN	IMEAN	TMEAN	GMEAN	BMEAN
CMEAN	.825 SD.064	.562 SD.062	.481 SD.055	.736 SD.065	.195 SD.057
IMEAN		.761 SD.054	.587 SD.060	.439 SD.065	.356 SD.048
TMEAN			.718 SD.060	.543 SD.057	.308 SD.052
GMEAN				.837 SD.000	.252 SD.049
BMEAN					.588 SD.000

12

	CMEAN	IMEAN	TMEAN	GMEAN	BMEAN
CMEAN	.856 SD.051	.582 SD.054	.526 SD.056	.767 SD.053	.243 SD.060
IMEAN		.797 SD.082	.615 SD.068	.455 SD.048	.391 SD.051
TMEAN			.757 SD.057	.547 SD.055	.376 SD.066
GMEAN				.869 SD.000	.260 SD.038
BMEAN					.589 SD.000

	CMEAN	IMEAN	TMEAN	GMEAN	BMEAN	13
CMEAN	.856 SD.051	.590 SD.059	.516 SD.061	.768 SD.064	.238 SD.057	
IMEAN		.792 SD.058	.623 SD.054	.487 SD.060	.422 SD.056	
TMEAN			.774 SD.054	.543 SD.060	.333 SD.055	
GMEAN				.882 SD.000	.243 SD.036	
BMEAN					.546 SD.000	

	CMEAN	IMEAN	TMEAN	GMEAN	BMEAN	14
CMEAN	.833 SD.061	.567 SD.054	.484 SD.053	.738 SD.070	.190 SD.054	
IMEAN		.733 SD.043	.593 SD.062	.426 SD.053	.378 SD.046	
TMEAN			.725 SD.049	.518 SD.044	.345 SD.045	
GMEAN				.838 SD.000	.241 SD.041	
BMEAN					.543 SD.000	

15

	CMEAN	IMEAN	TMEAN	GMEAN	BMEAN
CMEAN	.862 SD.052	.569 SD.053	.511 SD.062	.763 SD.070	.228 SD.052
IMEAN		.809 SD.000	.611 SD.062	.421 SD.054	.382 SD.080
TMEAN			.736 SD.054	.521 SD.058	.356 SD.057
GMEAN				.090 SD.000	.233 SD.024
BMEAN					.575 SD.000

16

	CMEAN	IMEAN	TMEAN	GMEAN	BMEAN
CMEAN	.801 SD.056	.509 SD.054	.447 SD.060	.699 SD.053	.167 SD.058
IMEAN		.762 SD.041	.562 SD.061	.414 SD.057	.298 SD.036
TMEAN			.694 SD.057	.515 SD.044	.271 SD.049
GMEAN				.844 SD.000	.240 SD.037
BMEAN					.649 SD.000

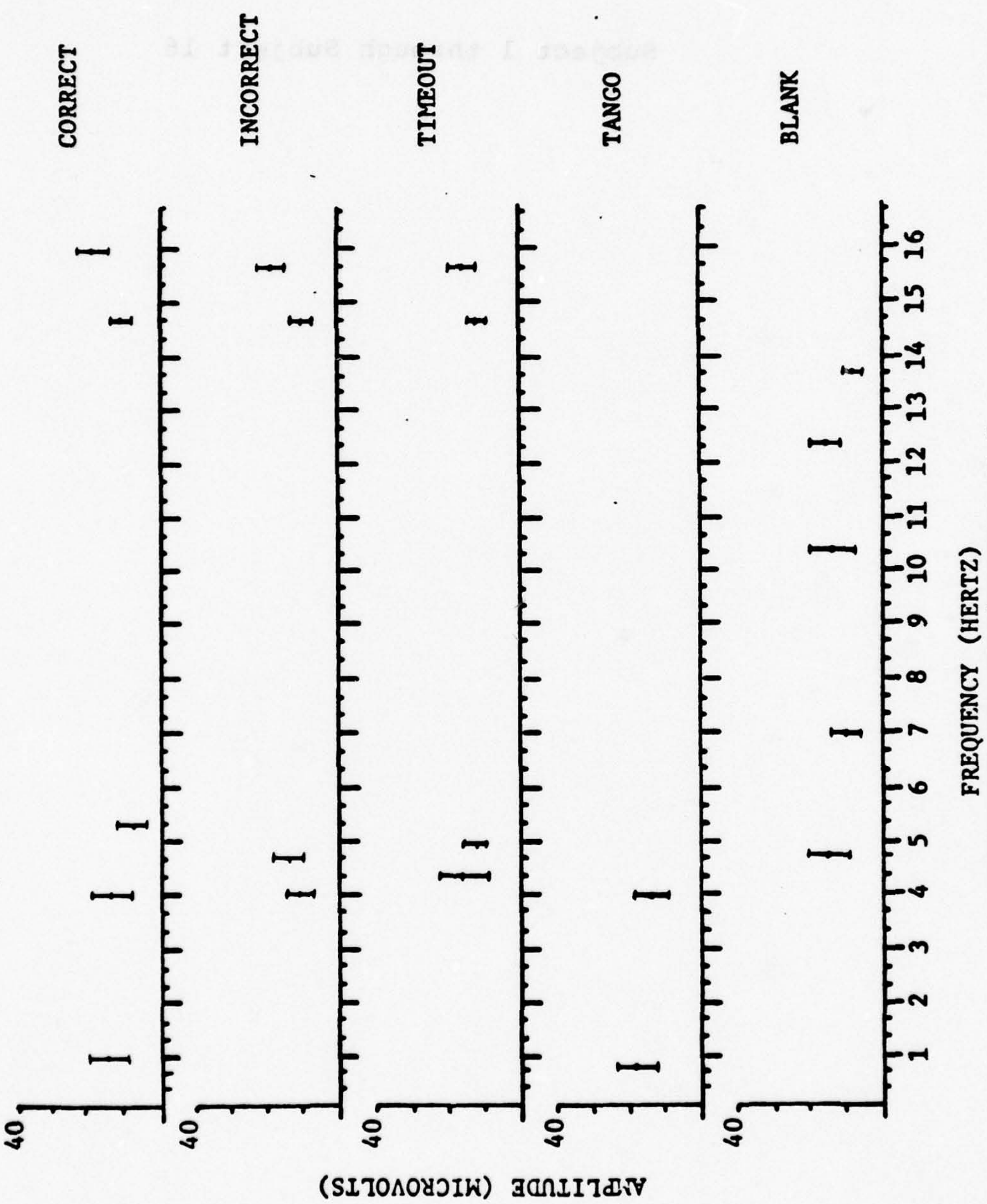
APPENDIX B

Subject Frequency/Amplitude Diagrams

Subject 1 through Subject 16

Subject Frequency/Amplitude Diagrams

Subject 1 through Subject 16



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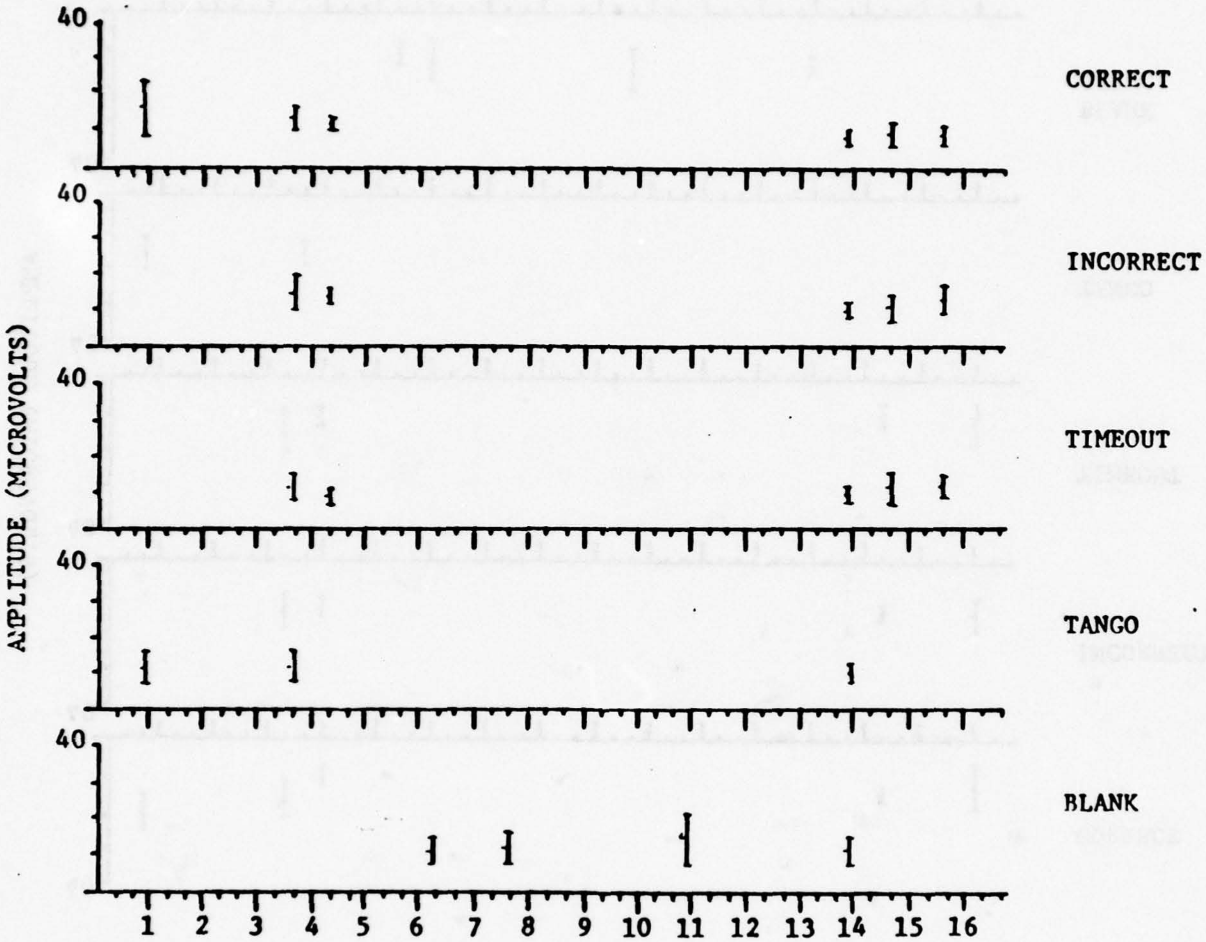

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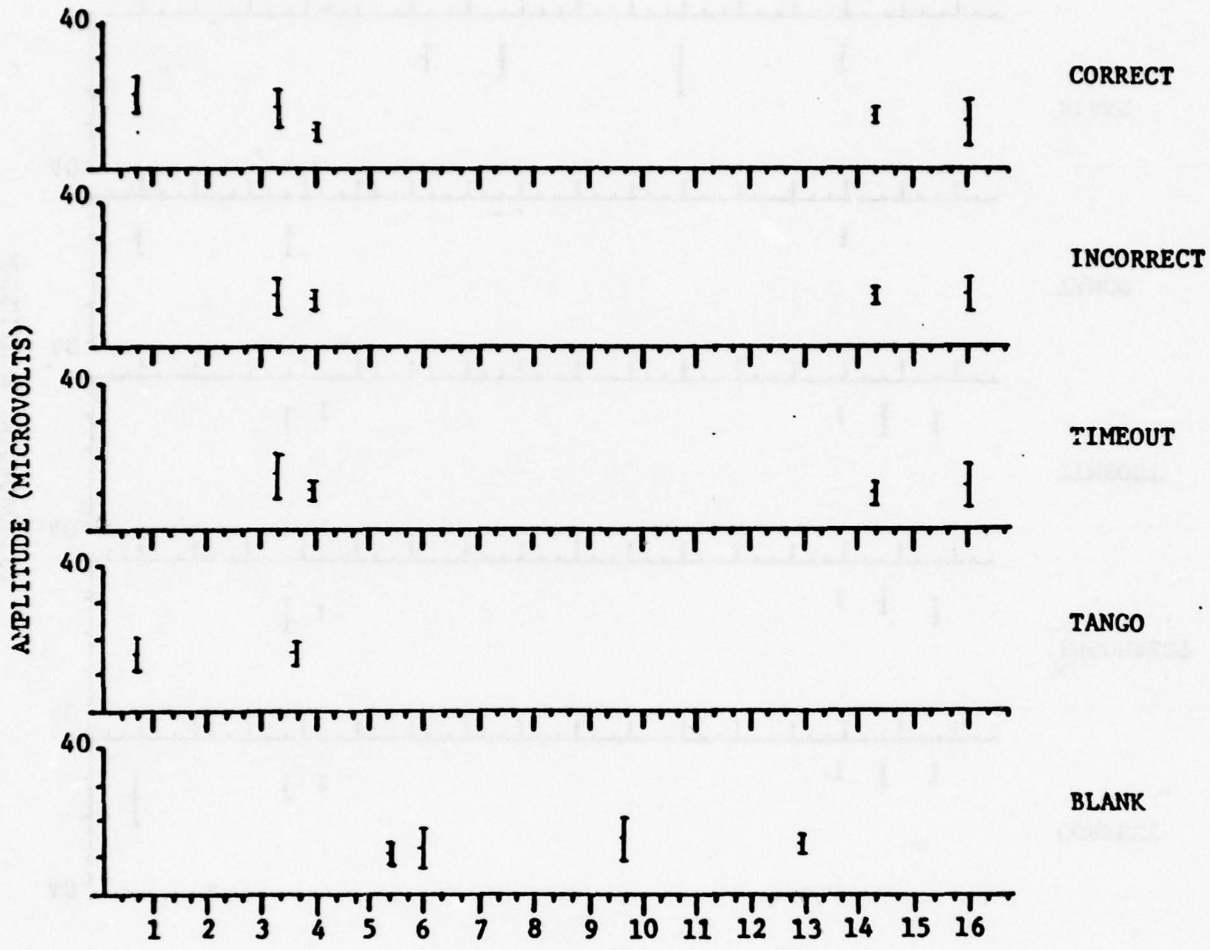

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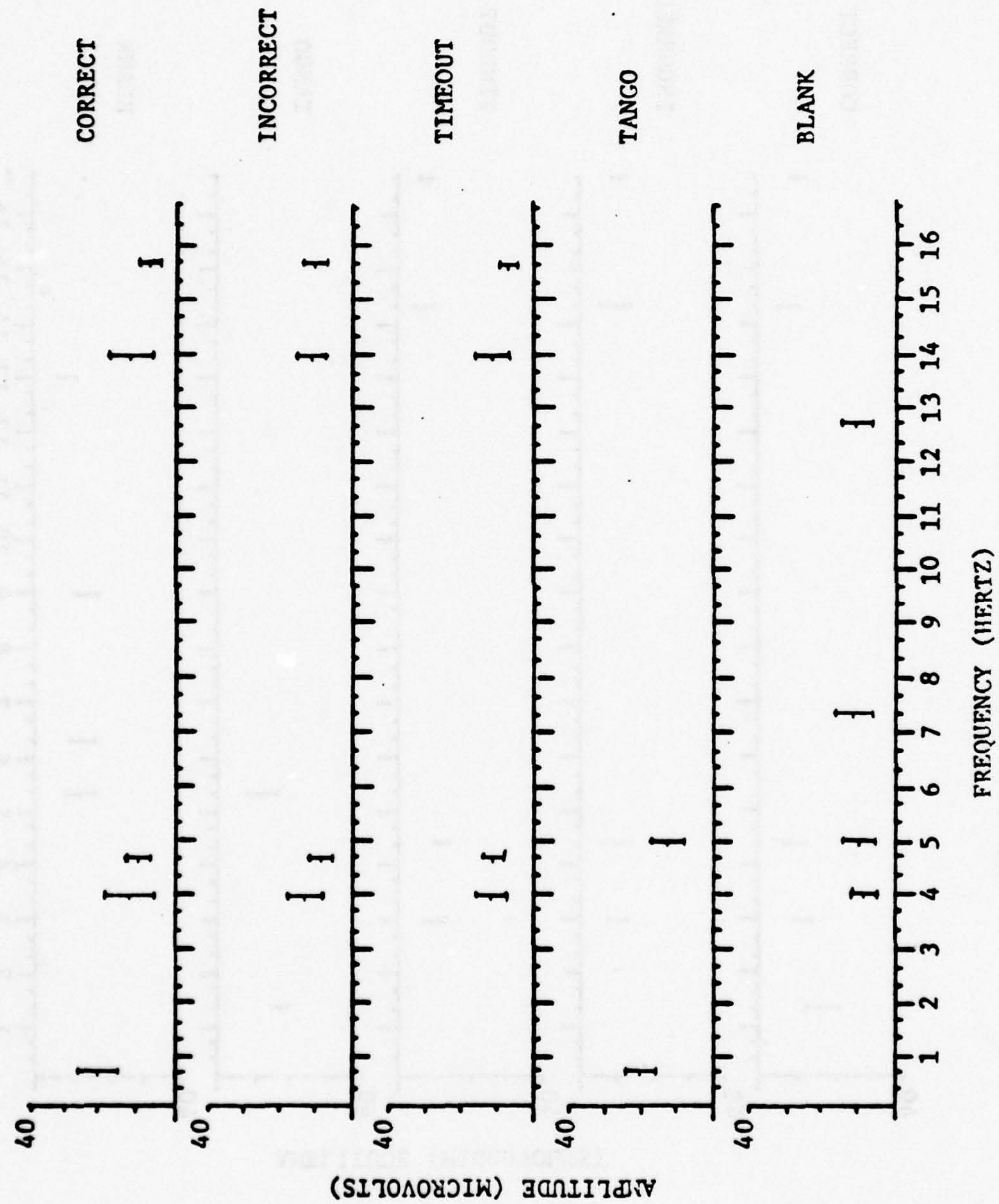

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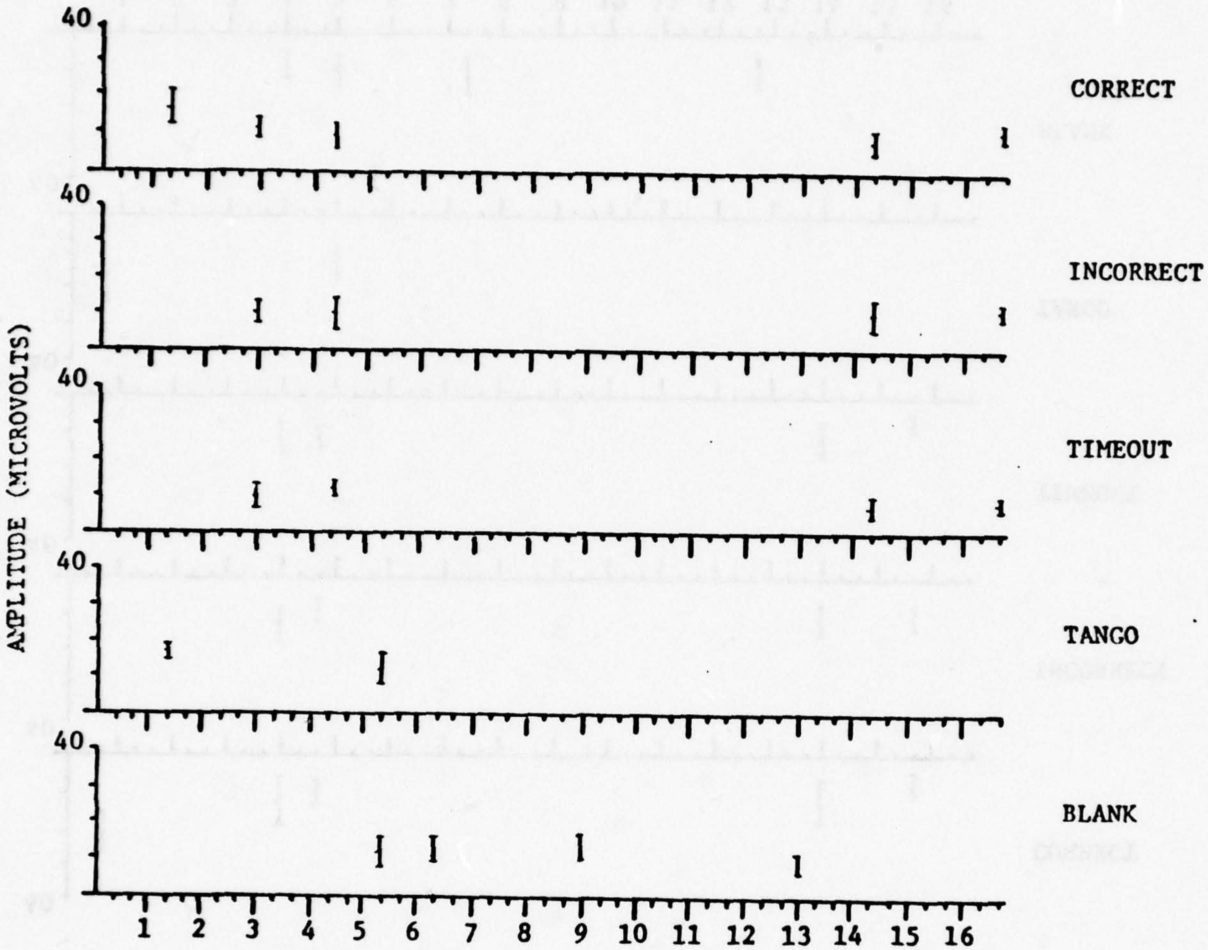

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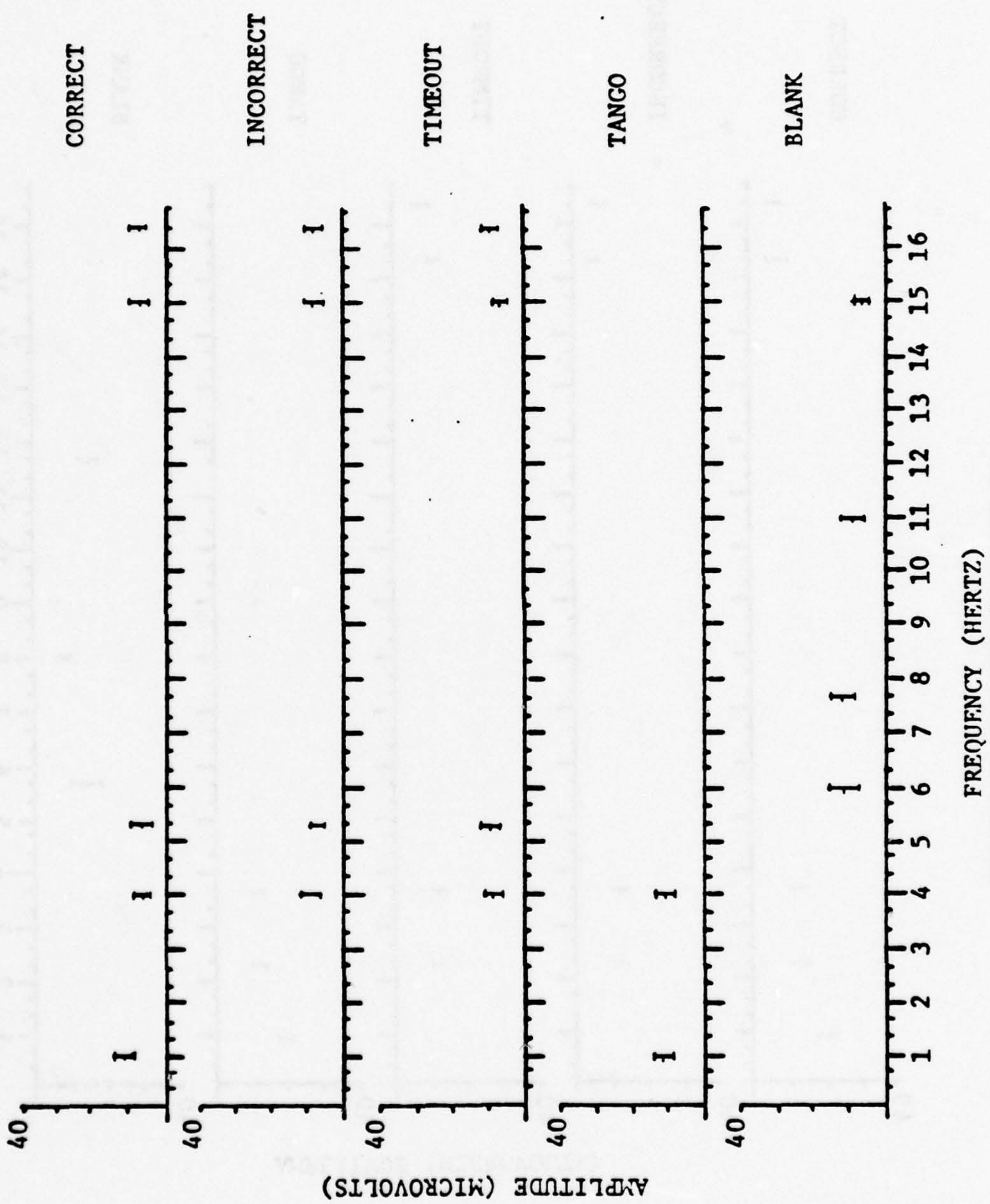

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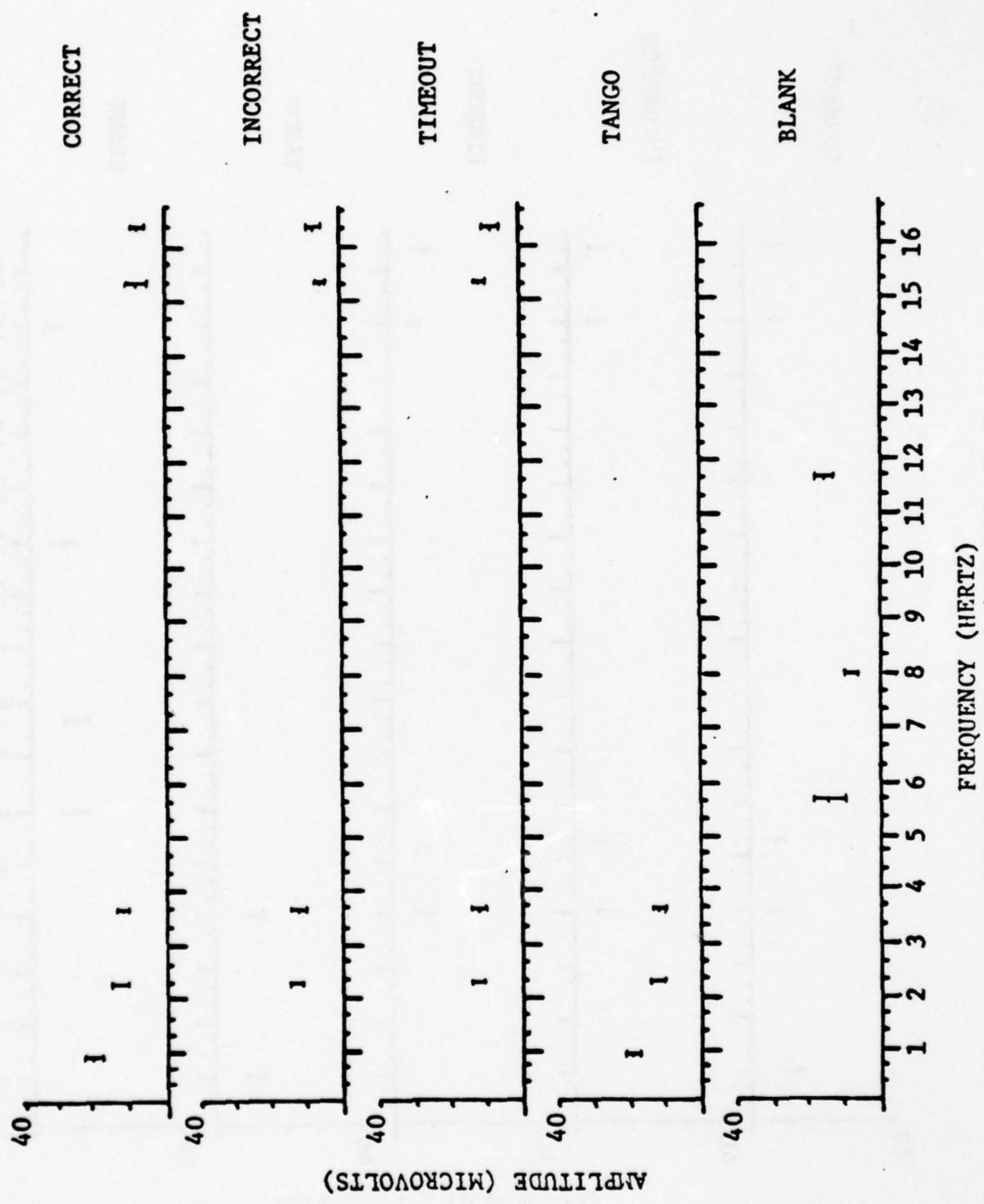

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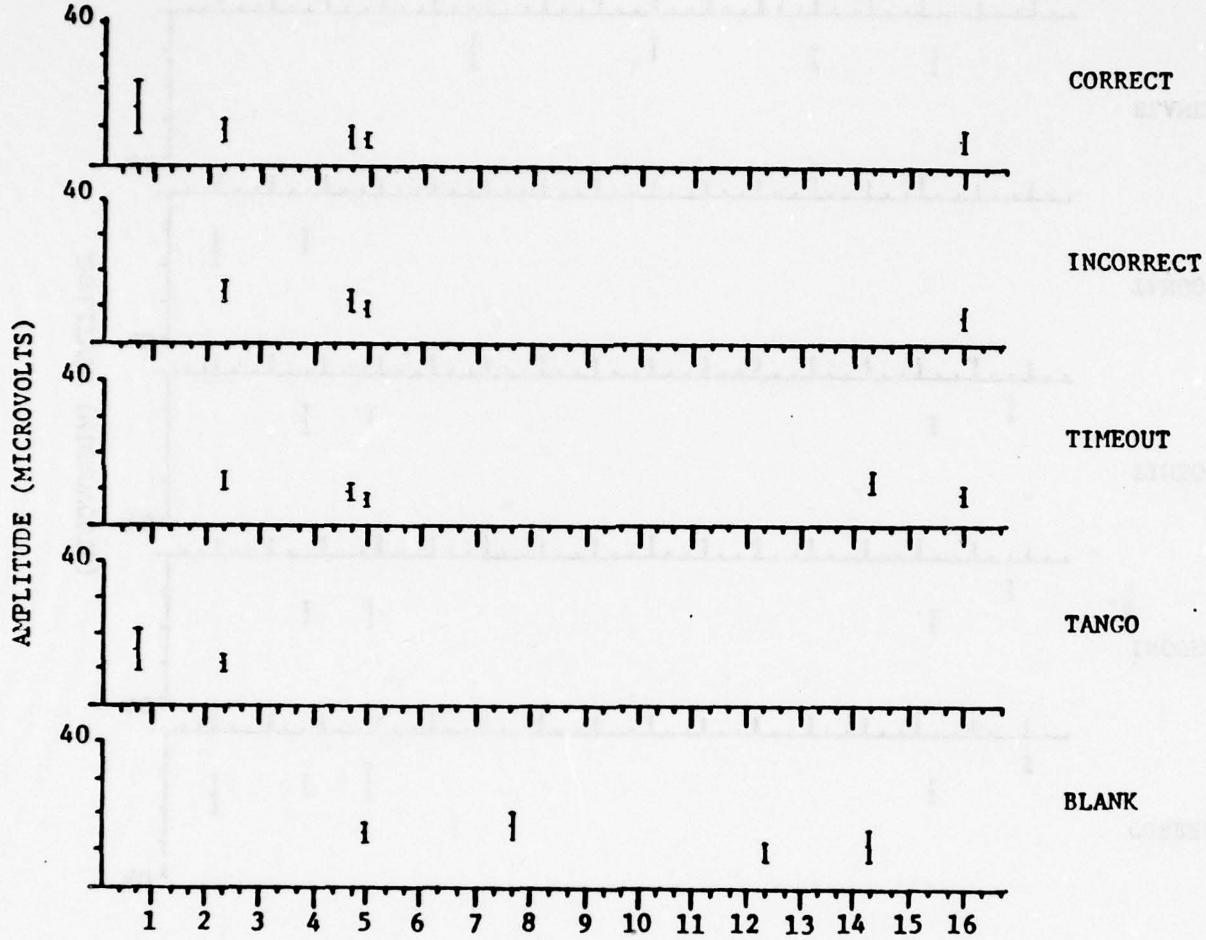

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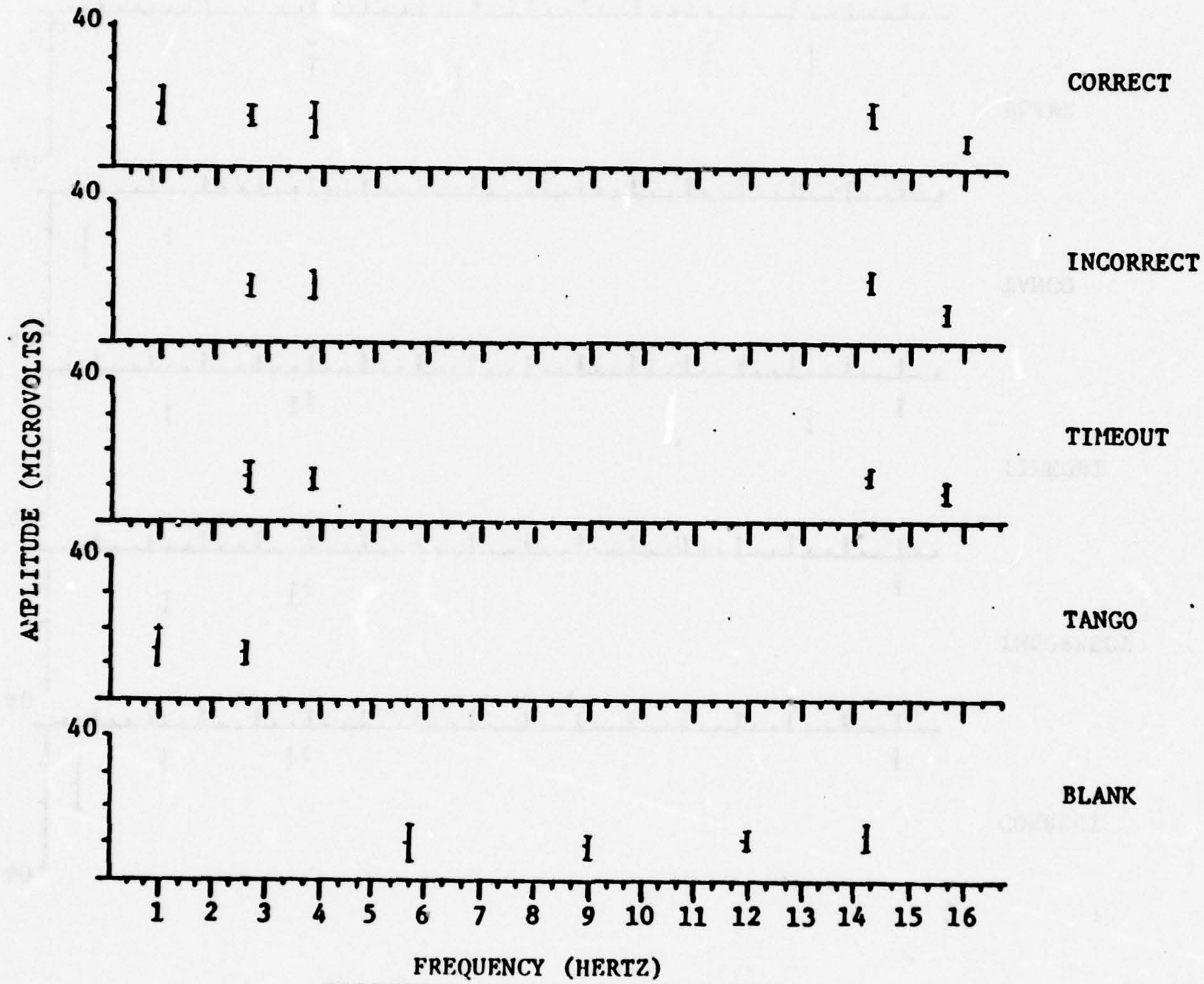

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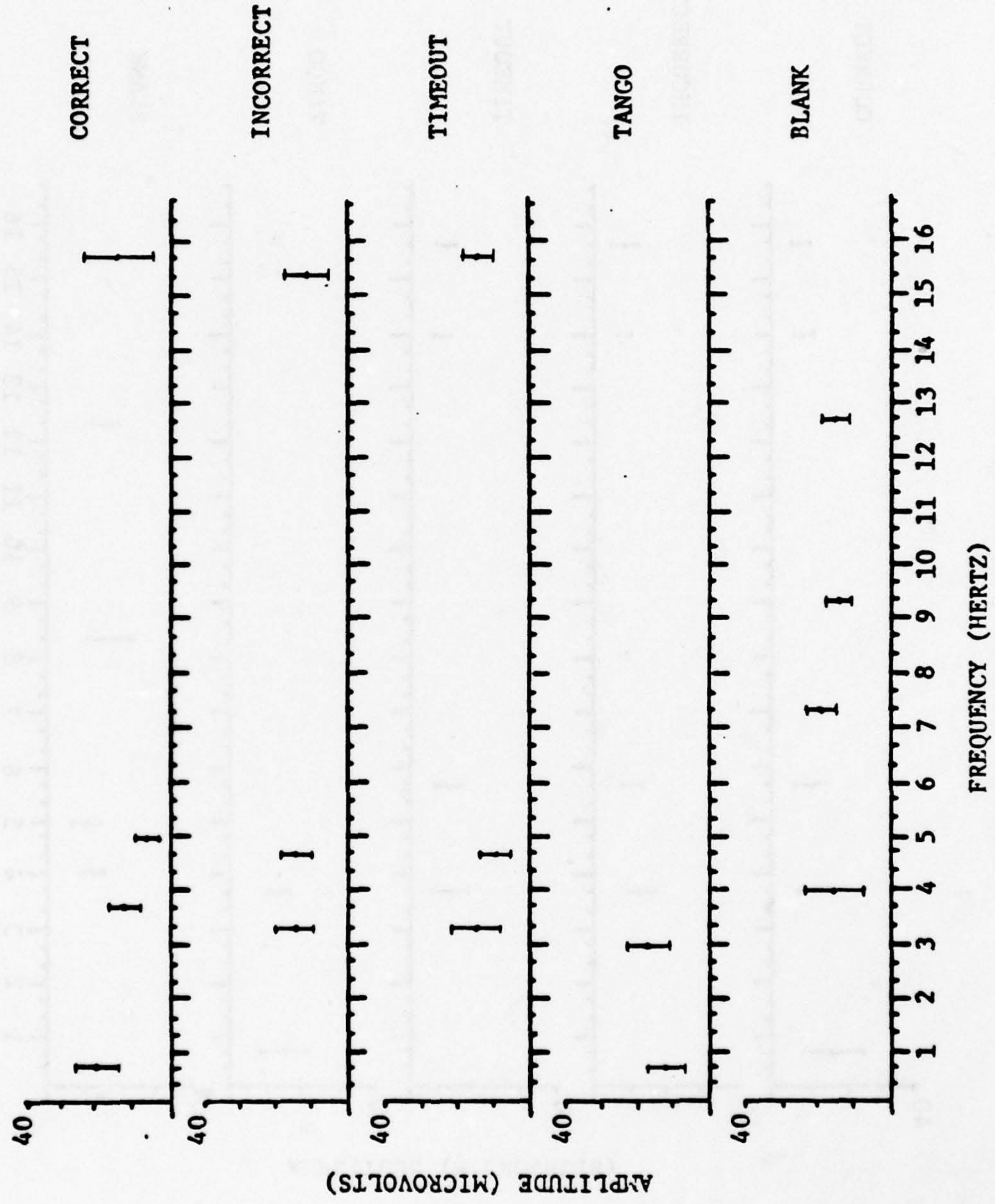

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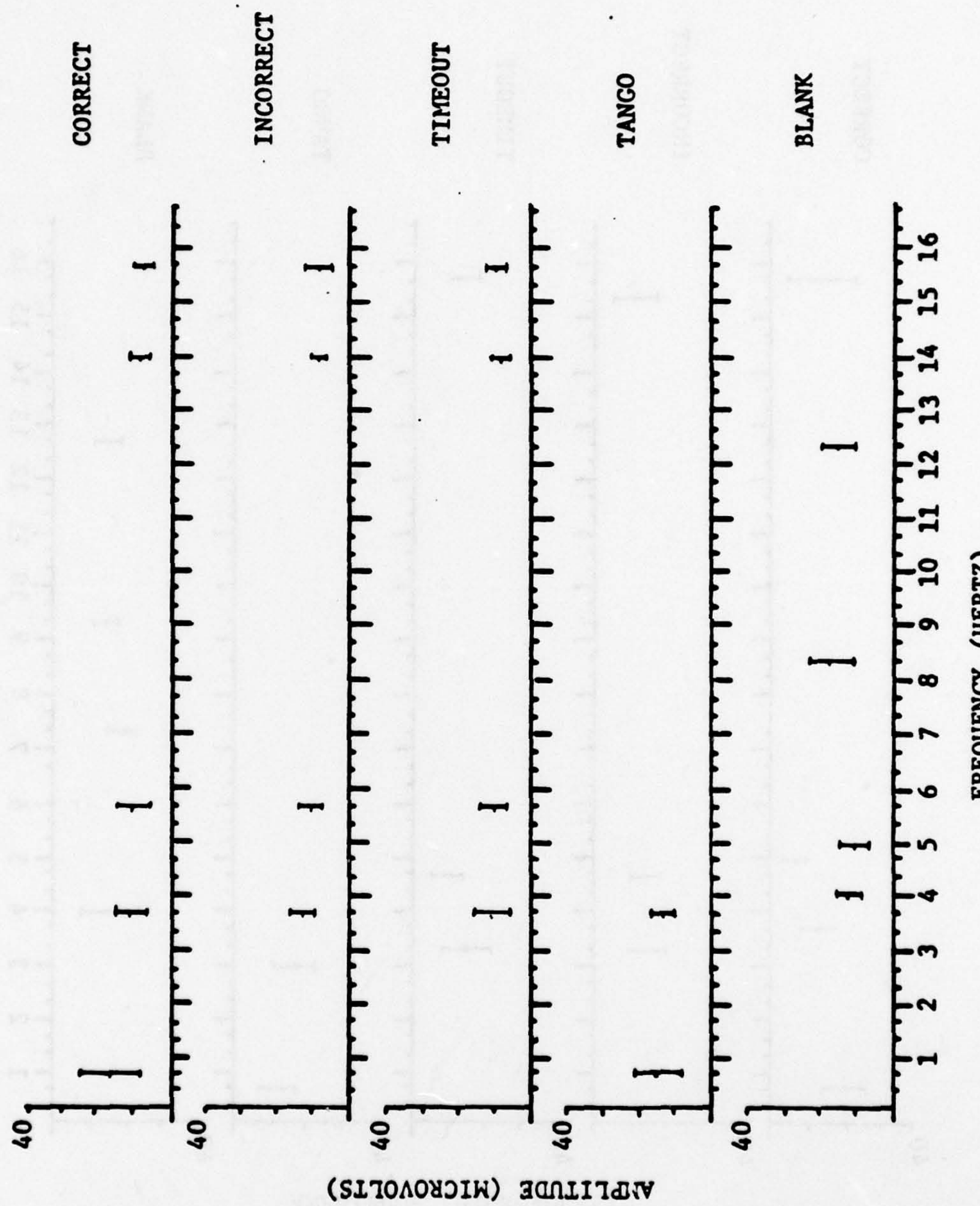

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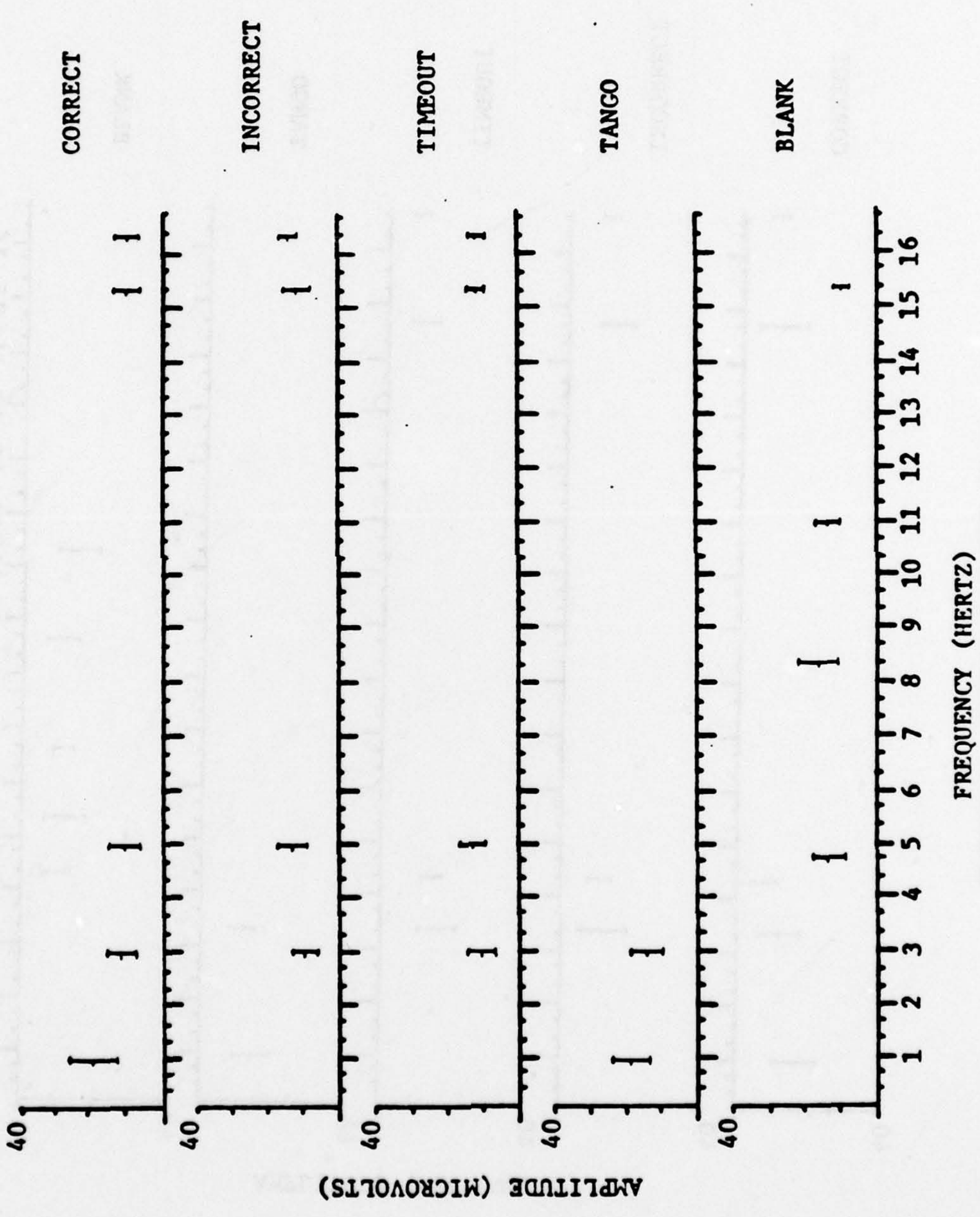

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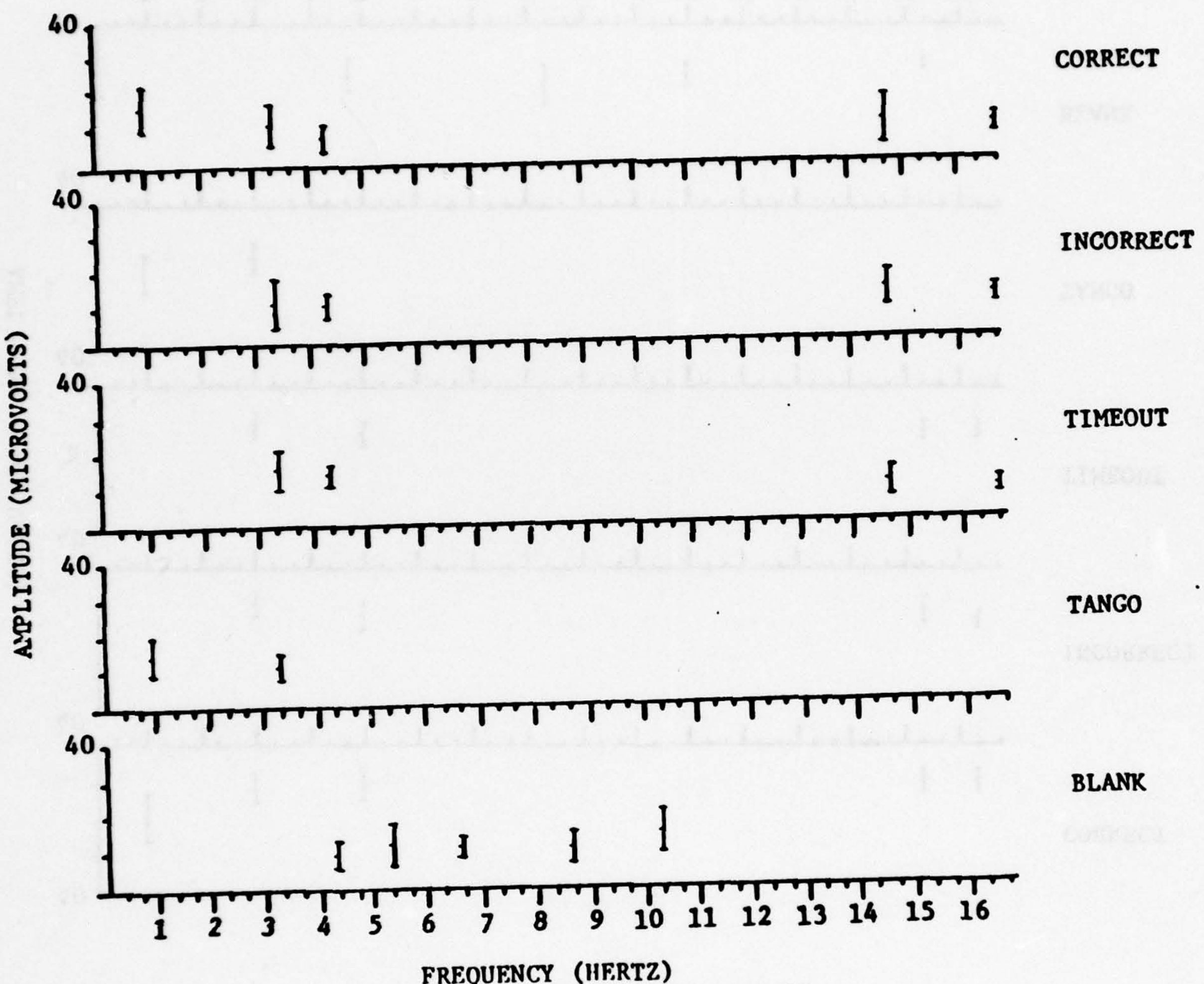

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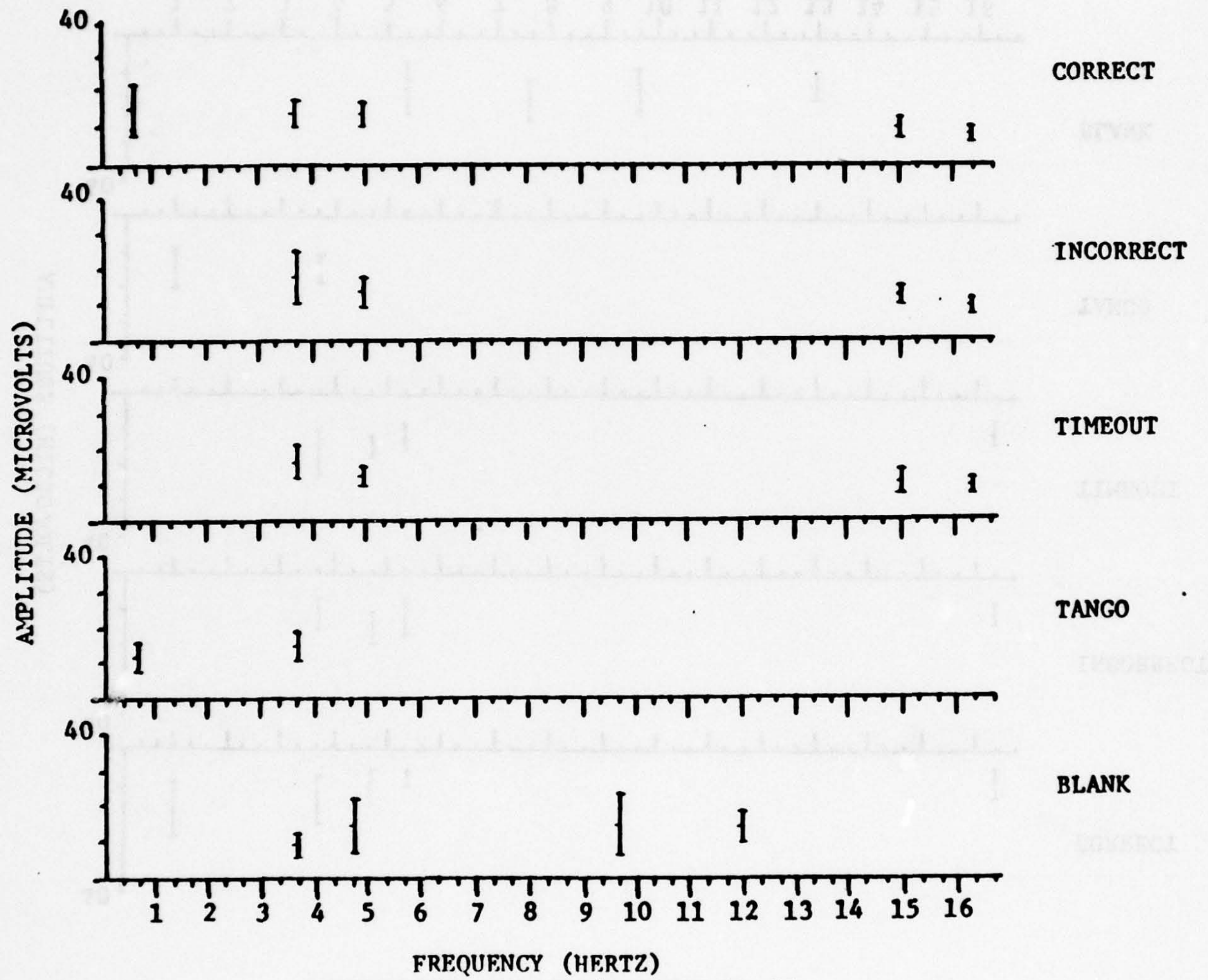

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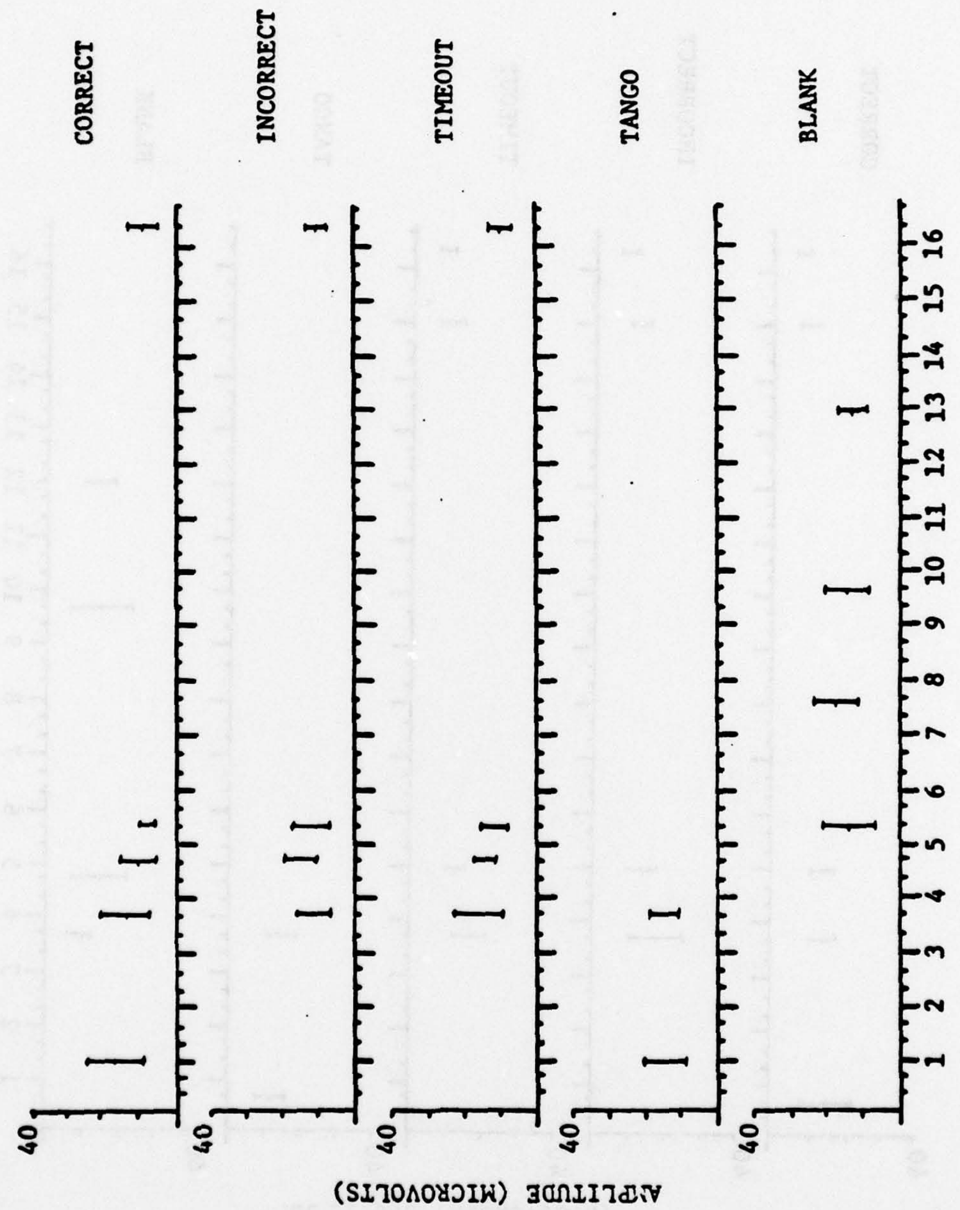

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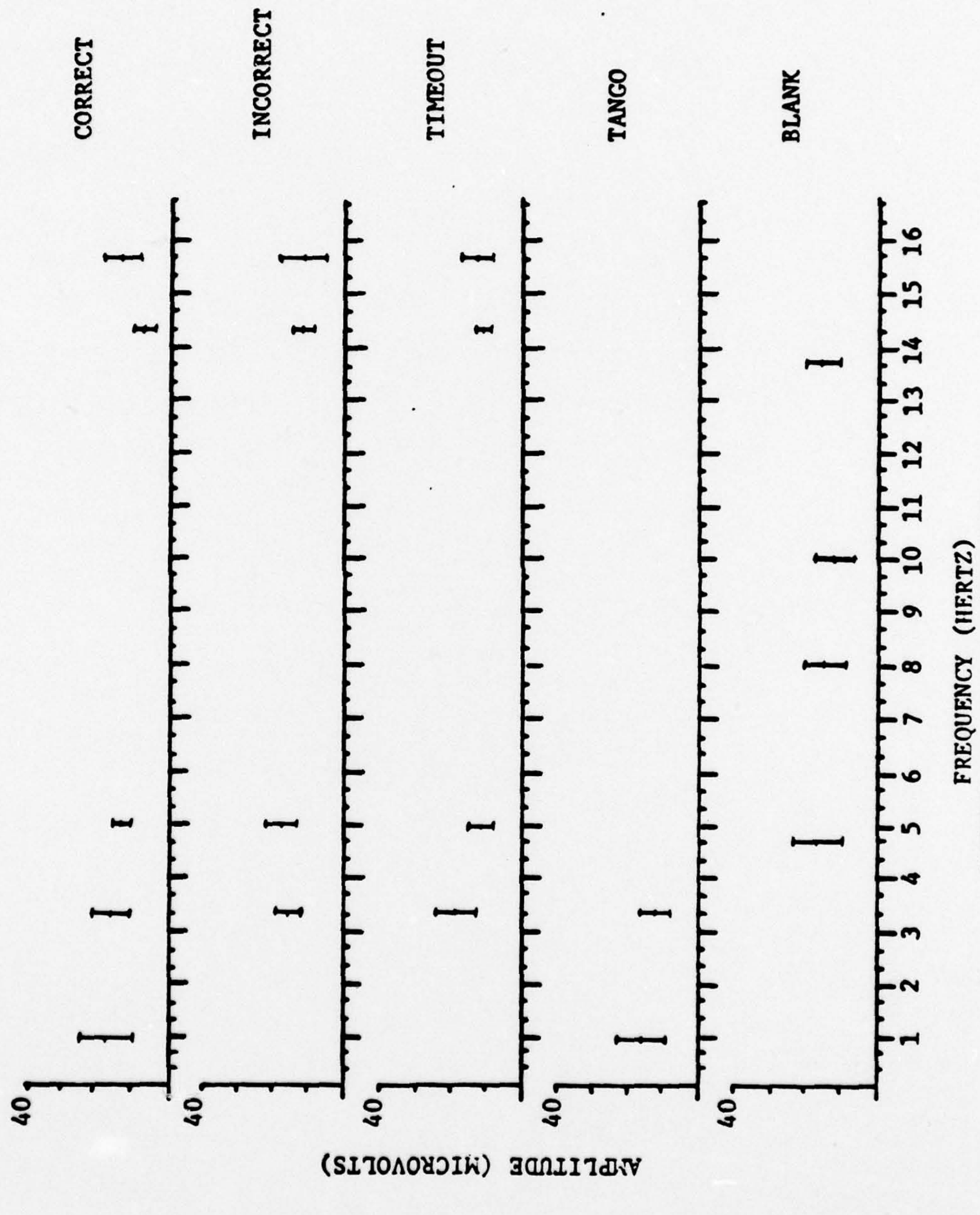

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